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THE McGRAW-HILL MAGAZINE OF NUCLEAR TECHNOLOGY

NUCLEONICS

September, 1947

FOUNDATIONS OF NUCLEAR PHYSICS

PRINCIPLES OF NUCLEAR PARTICLE DETECTION

ISOTOPE TECHNIQUES IN BIOCHEMISTRY—I

QUANTUM MECHANICS FOR NUCLEAR TECHNOLOGY—I

TRAINING IN NUCLEAR TECHNOLOGY

ELECTRONIC INSTRUMENTS FOR USE WITH G-M TUBES

RADIOISOTOPE PRICES

INDUSTRY AND NUCLEONICS

MANHATTAN DISTRICT DECLASSIFIED DOCUMENTS

PRE-WAR NUCLEONICS LITERATURE

NUCLEONICS

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of Nuclear Technology
with which is incorporated
Atomic Engineering and *Atomic Power*

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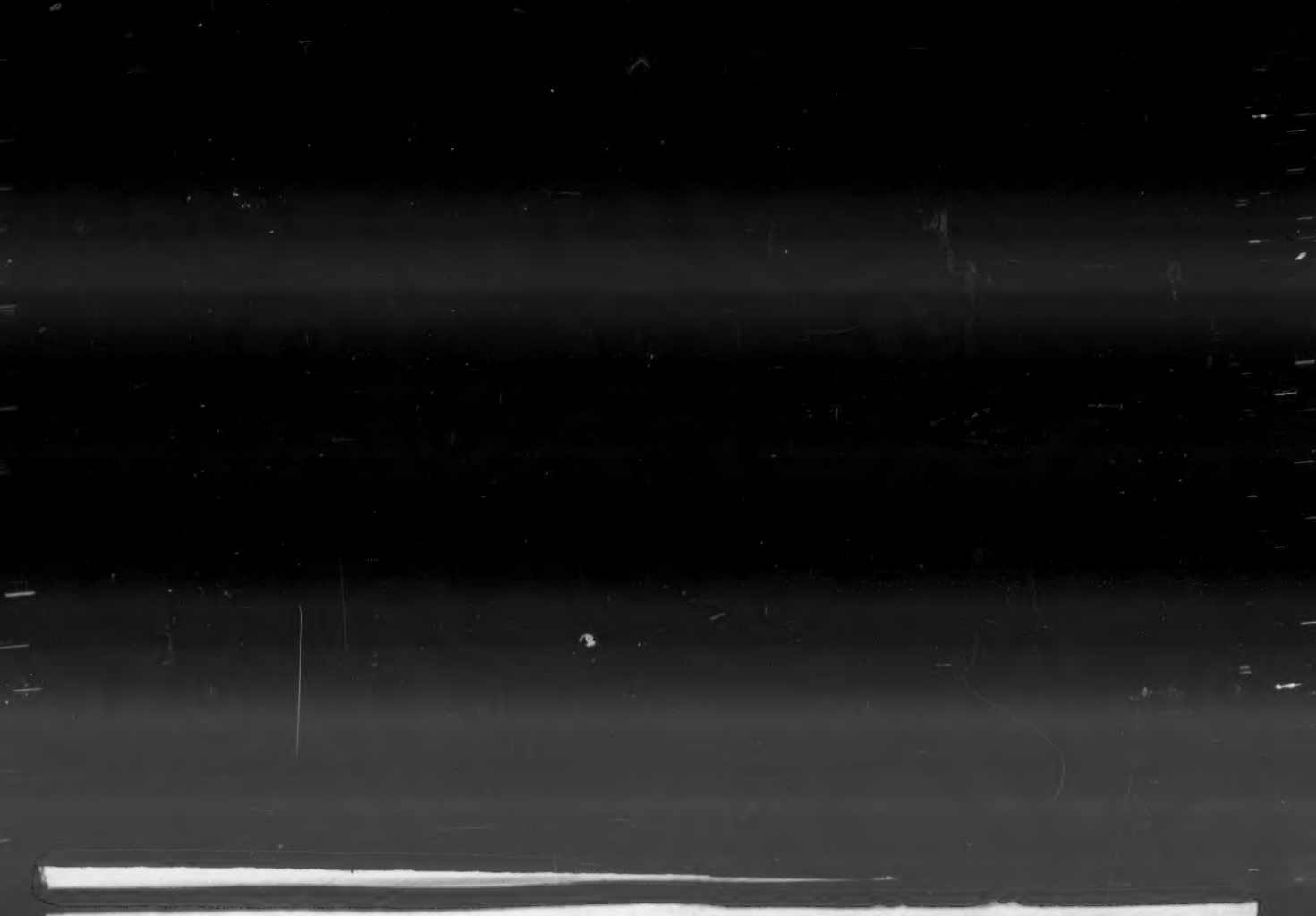

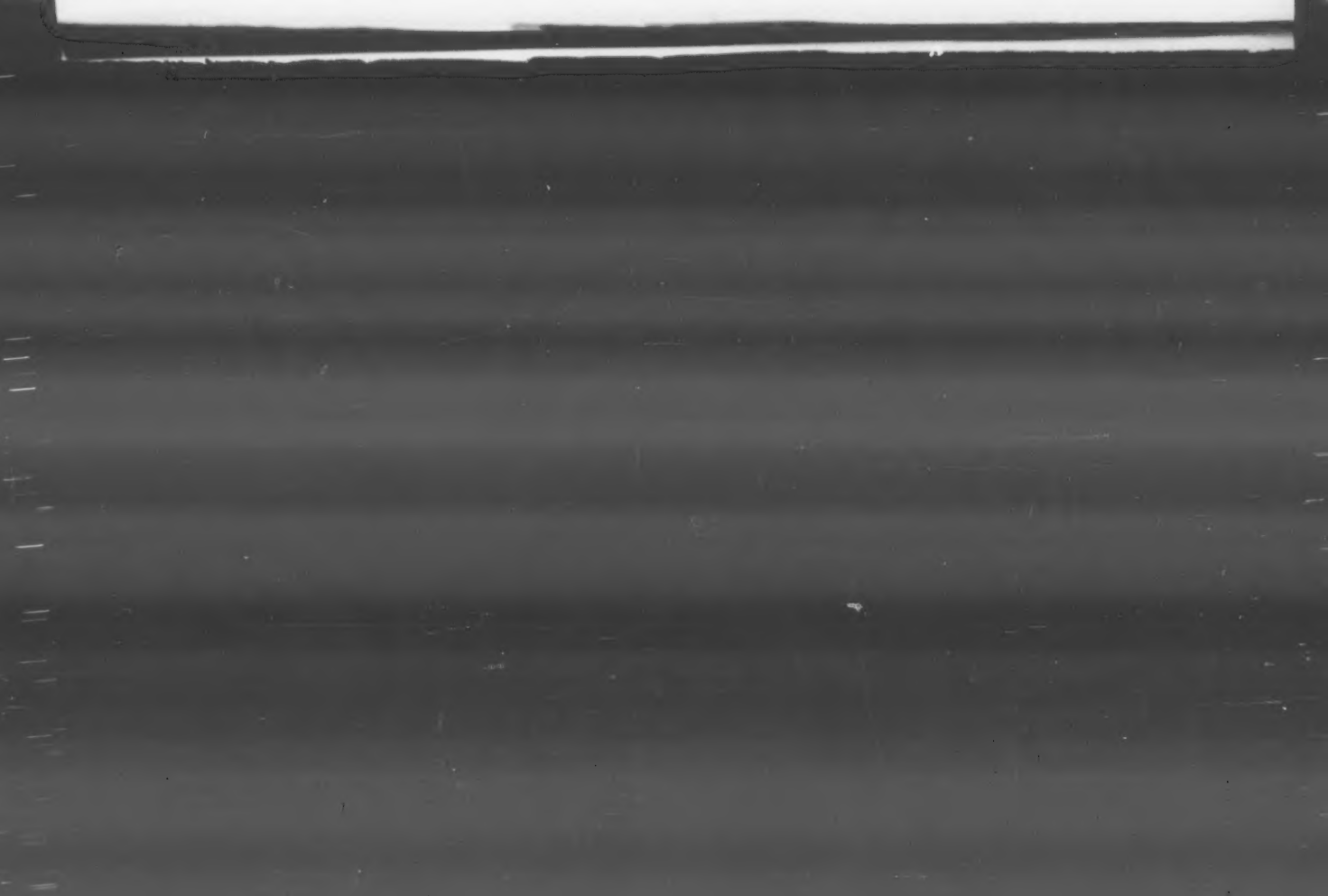

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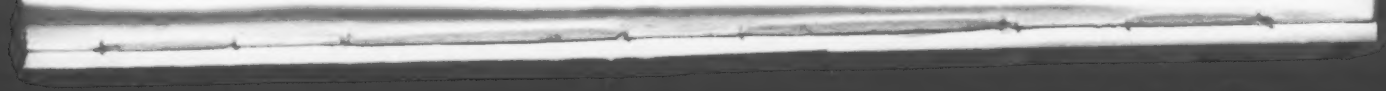

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NUCLEONICS

THE McGRAW-HILL MAGAZINE OF NUCLEAR TECHNOLOGY

What Is Nucleonics?—The Technology

THE SCIENCE of the rearrangement of nuclear particles has now reached maturity. It has given birth to an associated nuclear technology embracing all methods and results of applying nuclear particles to useful ends.

To the proton and neutron has been given the common name of *nucleon*. Nucleonic physics, therefore, has come to be understood as the science of those changes in which there occurs a rearrangement, but no change, in the total number of nucleons present. Radioactivity, nuclear disintegration, nuclear fission, and nuclear synthesis are the processes comprehended by this science. Nucleonics is defined as the technology for utilizing these processes, and to this technology the publication NUCLEONICS is devoted.

The chain-reacting pile and the atomic bomb offer dramatic evidence that, in respect to rates of reaction and heats of reaction, nucleonics is now nearly as fully developed as chemistry itself. However, as is also the case with chemical processes, our descriptions of nuclear processes are still largely empirical. There exist no comprehensive theories of either chemical or nuclear processes which can claim to be nearly so logically and experimentally satisfactory as the theories of gravitation and electromagnetism. This is the fact that underlies the altogether different purposes of nucleonic, or "atomic-energy," research, and contemporary nuclear physics research.

From the physicist's point of view, nuclear forces take their place alongside electromagnetic and gravitational forces as the third fundamental universal force to come under man's control. As a fundamental scientist, the nuclear physicist is dedicated to the development of a conceptual framework within which he can logically explain the interactions of these nuclear forces. The majority of the world's nuclear physicists are now seeking clues to the structure of this missing framework from studies of the internal transformations of neutrons and protons—usually termed subnucleonic physics.

"Subnucleonics" is often called high-energy physics, since effective energies of 100 Mev (million electron volts) and 1 Bev (thousand million electron volts) are probably needed to cause the nucleon to undergo observable internal transformations. At present, subnucleonics includes such subjects as cosmic-ray physics, neutrino physics, meson theory, and fundamental field theory. As fundamental research goes on, these disciplines will contribute more and more to nuclear technology, and eventually will be incorporated into nucleonic explanations of radioactivity, nuclear fission, and other "low-energy" nuclear reactions.

There also exists the distinct possibility that subnucleonics will show us how to transform all forms of matter, gram for gram, into equivalent energy. The Einstein mass-energy principle tells us we should not be content with fission of a heavy nucleus that releases only one part in a thousand of the energy locked up in its mass. In any event, continued progress in high-energy physics means that subnucleonics will also someday pass into the realm of nuclear technology.

Meanwhile, nucleonic physics, the science of the rearrangement of nuclear

particles, is today as accessible to technological exploitation as chemistry, the science of the rearrangements involving the outer electrons surrounding the nuclei of the elements. Progress in nucleonics now depends solely on the rate at which capital and technical manpower are brought to bear on it.

What Is Nucleonics?—The Magazine

IF NUCLEAR TECHNOLOGY had come of age in the same gradual, unspectacular way as other applied sciences, engineers and scientists with common interests in this field would undoubtedly have followed the usual historical procedure of establishing national nucleonics societies.

They might have published a "Journal of the American Nucleonics Society," a "Zeitschrift für Nucleonik," and similar national periodicals for recording and disseminating advances in their technology. Although many psychological and political conditions have thus far delayed the founding of these societies, it is now generally recognized that establishment of a well-rounded journal of nuclear technology is long overdue.

The McGraw-Hill Publishing Company is founding NUCLEONICS to make available a logical medium for the cross-fertilization of technical advances in all phases of nuclear technology. To its readers, this journal will bring a monthly symposium on the applications of nuclear physics. For its contributors, it will provide a meeting place for the exchange of ideas between engineers, physicists, chemists, life scientists and teachers.

Research and review articles contributed to NUCLEONICS will be accepted and edited in accordance with the standards of merit governing leading engineering and scientific publications. All contributions will be refereed by qualified reviewers active in the particular field, and authors will receive honorariums for papers published.

In addition to its function as an international clearing house for the announcement of new application techniques of nuclear energy, NUCLEONICS will report the development, activities, and economics of nucleonic industries.

In the final analysis, the responsibility for NUCLEONICS' doing full justice to its field lies with its readers and contributors. Its editors are merely intermediaries who succeed to the extent that they can present an undistorted reflection of all aspects of the field as it is.

TO SUBSCRIBERS

This first issue of the magazine NUCLEONICS is the outgrowth of plans initiated two years ago with publication of several issues each of three slim mimeographed "magazines," ATOMIC POWER, ATOMIC ENGINEERING, and NUCLEONICS. It would be unfair to compare their fairly superficial contents with this issue, but they did bring us many suggestions from potential readers that have helped make NUCLEONICS better.

We earnestly solicit your further suggestions. What do you think of our content, our type faces, our size? We want to make NUCLEONICS steadily more useful to you; *our policy is to plough back into improvements any excess of revenues over actual out-of-pocket costs during this development stage,* guided by the needs and ideas of you and our other readers. —*The Publisher*

FOUNDATIONS OF NUCLEAR PHYSICS

Because of his historic contributions to many fields of science and technology, NUCLEONICS features this introduction to nuclear physics by Dr. E. U. Condon—key figure in the United States wartime development of nuclear energy, member of the National Academy of Sciences, and president of the American Physical Society in 1946

By E. U. CONDON
Director, National Bureau of Standards

WITH THE ESTABLISHMENT of a journal devoted to the subject, there can be no doubt that nuclear technology has come of age. On this occasion, it seems appropriate to review the history of nuclear physics and something of the way in which the science back of nuclear engineering started. So that it need never appear on these pages again, perhaps it is well to record, too, the inevitable pun that "nuclear" physics is really "unclear" physics.

About 50 years ago, the electrical nature of matter and the atomic nature of electricity were first recognized. Men then began to speculate on how this electricity was arranged in the atoms. In other words, they tried to interpret the known properties of atoms in terms of a structural hypothesis.

Positive Particles

The most decisive step in this direction came in 1912 when the experiments of Sir Ernest Rutherford showed that the positive electricity in the atom must be concentrated in a single particle whose diameter could not be greater than 10^{-12} cm. He studied the distribution in angle of the scattering of alpha particles from radium by thin foils of various substances. The alpha particles are known to be high-speed, positive helium ions. Before Rutherford's experiments, it was often supposed (on no evidence) that the positive electricity was more or less continuously distributed over the whole region occupied by the atom, which is a sphere about 10^{-8} cm in diameter.

The charge on an electron is now known to be close to 4.8×10^{-10} esu. Therefore, since 1 esu = 300 v, the electric potential in volts, V, at a distance r from such a charge (where r is measured in 10^{-8} cm) is

$$V = \frac{4.8 \times 10^{-10} \times 300}{r \times 10^{-8}} = \frac{14.4}{r}$$

In this article, electric charges will be expressed in terms of the electronic charge as the unit. The amount of positive and negative charge in any atom in this unit is known as the atomic number for that element, usually denoted by Z. Thus Z equals 2 for helium and 79 for gold.

If the positive electric charge in a gold atom were spread out over a sphere about 10^{-8} cm in radius, the greatest electric potential at any point within the space, even in the absence of the negative electricity, would be less than 10,000 volts.

It is known from experiments on their deflection in electric and magnetic fields that the alpha particles from radium have energies corresponding to an acceleration between two and three *million* volts. A particle of this much energy would go right through the gold atom and be only slightly deflected. Yet Rutherford found experimentally that a very few of the alpha particles were scattered by gold through very

large angles, even up to 180 deg, that is, a complete reversal of direction. From this he concluded that the positive electricity in the atom was not spread throughout the volume of the atom but must be confined to a much smaller region in order that its electric potential be great enough to produce the observed large-angle scattering of alpha particles.

He found that the actual scattering was quantitatively accounted for, in great detail and for many different elements, by supposing the alpha particles to be scattered by their motion according to mechanical laws under the inverse-square-law electrostatic force between the positively charged alpha particle and the very small positively charged and massive core of the atom of the scattering material. This very small central core of the atom, Rutherford called the *nucleus*.

Atom Electrically Neutral

His conclusions have stood the test of time through a vast and ramified development. The atom of the chemical element whose atomic number is Z consists of a heavy central nucleus about 10^{-12} cm in diameter, carrying a positive electric charge of Z units, and surrounded by Z electrons, each carrying a negative electric charge of one unit. Thus, the whole atom is electrically neutral. The mass of such an atom is denoted by A on a scale in which the most abundant kind of oxygen atom is arbitrarily assigned the exact value 16. In terms of this unit of atomic weight, each electron has a weight of about $\frac{1}{1840}$, so that nearly all of the mass of the atom is in the positively charged nucleus.

The simplest atom of this kind is the hydrogen atom for which $Z = 1$, and $A = 1$ (approximately). Its central nucleus is the smallest known and has a special name. It is called a *proton*. The exact values of A are always close to an integer. The significance of the exact values is considered later.

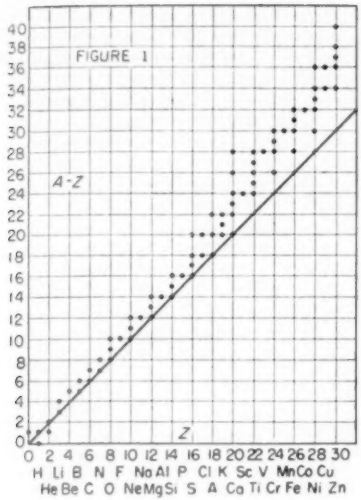
It is the number Z which determines the chemical properties of an atom. It was soon discovered that the atoms of most chemical elements are not all of the same weight. Atoms of the same Z, but differing weights A, are said to be *isotopes*. The simplest example is provided by hydrogen itself. Its heavy isotope was not discovered until 1932 by Urey, Brickwedde, and Murphy. They found that about one part in 5,000 of ordinary hydrogen consists of atoms for which $A = 2$; that is, they are about twice as heavy as the atoms of ordinary hydrogen. Likewise it was found that neon is a mixture of three isotopes for which $A = 20$, 21, and 22 approximately. It is now known that uranium is a mixture of three isotopes for which $A = 234$, 235, and 238.

For the purposes of classical chemistry, all isotopes of an element have the same properties. Chemistry in the usual sense depends only on Z, not on A. Very careful study shows extremely slight dependence of chemical properties on the weight, but these effects are so small that they do not mar the truth of the statement.

For nuclear physics and nuclear engineering, A is every bit as important a property as Z. We are naturally led to consider what kinds of atoms occur in nature as specified by the pair of numbers (A, Z), the first giving the atomic weight to the nearest integer, the second giving the nuclear charge which is exactly an integer. In Fig. 1, a graph is made of the values of $(A - Z)$ as ordinates and Z as abscissas. A black dot shows the values of (A, Z) for which stable atoms occur in nature.

Such a graph shows the general tendency is for A to be about equal to $2Z$ for elements occurring in nature (except for light hydrogen), and for A to be greater than $2Z$ for elements with Z greater than about 20. Evidently there must be something more in the nucleus than the Z protons needed to give it its charge, for a nucleus consisting only of Z protons would have an atomic weight equal to Z or about half the actual atomic weights occurring in nature.

Curiosity prompts the asking of these questions: (a) What else is in the nucleus to make up the extra weight not



accounted for by the protons? (b) Why are there only certain elements occurring in nature? For example, why do we not find a hydrogen of mass $A = 10$ or a uranium of mass $A = 100$? (c) What holds the particles together in an atomic nucleus? (d) What special properties do the very heavy elements have that make them break up spontaneously by throwing off helium nuclei, otherwise known as alpha particles? (e) Since some naturally radioactive elements throw off high-speed electrons with energies so great that we must suppose that they came from inside the nucleus, does this not show that there are electrons in the nucleus?

At the start of this century, theoretical study of the continuous spectrum of radiation from hot bodies led Planck to the radical hypothesis that light did not behave entirely like a continuous wave motion, but had some of the attributes of a stream of particles. These individual particles of light were called *light quanta*, and the associated theoretical developments were known as the *quantum theory*.

Soon after Rutherford was led to the idea of the nuclear atom by his studies of the scattering of alpha particles by thin foils, Niels Bohr began to study the orbital motion of the electrons surrounding the nucleus. He found that by an appropriate application of the ideas of quantum theory to these orbital motions he had the clue to the interpretation of the structure of the line spectra of atoms. Thousands of wave-lengths of light emitted by atoms, wave-lengths which can be measured to six-decimal-place accuracy, fitted nicely into the highly detailed theoretical scheme which developed from Bohr's ideas.

This development of the understanding of the motions of the electrons around the nucleus occupied the principal attention of physicists and chemists in the period from 1914 to 1930. A complete interpretation was given not only to the vast amount of data of spectroscopy, but also to a basic understanding of the main facts of the periodic system, of the different types of chemical bond, of the electronic structure of molecules, of the electron theory of metals and of the basic mechanisms of chemical reactions. Those were fruitful years.

Quantum Mechanics Discovered

All was not smooth sailing during this period. Physicists started out with the idea that the motions of the electrons could be understood by classical Newtonian mechanics with some minor patchwork changes occasioned by the ideas of quantum theory. But matters proved to be not that simple. By 1925, this view had pretty well exhausted itself and it was necessary to reformulate completely the ideas of atomic mechanics. Quantum mechanics was discovered from purely theoretical considerations, leading to the idea that the motion of electrons in atomic systems was somehow governed by a wave motion. Just as light was recognized as having some of the attributes of both a stream of particles (that is, light quanta) and continuously propagated electromagnetic waves, so a stream of electrons was now understood to have some of the attributes of both a simple stream of

particles and a wave motion. This idea was brilliantly verified in the experimental discovery in 1927 of electron diffraction by Davisson and Germer in New York and by G. P. Thomson in England.

Concerning the physics of the nucleus, it may be said that the first and most decisive step in the modern period came in 1928 with the application of the quantum theory to the interpretation of natural radioactive disintegration of the heavy elements by the emission of alpha particles. This was done quite simultaneously and independently by Gamow, a Russian, working in Göttingen, and by Gurney and the writer, working at Princeton.

Consider the atomic species U^{238}. The atoms of uranium now remaining on earth are what is left from an original larger stock formed, somehow, geological epochs ago. The average life of a uranium atom is 6.75×10^9 years or 2.14×10^{17} sec.

Uranium Disintegration Rate

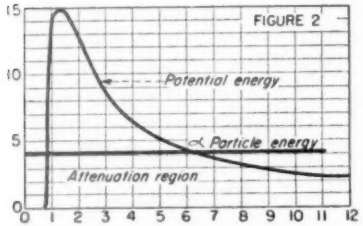
There is no way of knowing when a particular uranium atom will disintegrate. Some have done so long ago and are no longer with us. Others will not do so for billions of years. There is nothing we can do which affects this rate. Radium disintegrates much more rapidly. The average life of its atoms is only 2440 years, so there would not be any appreciable amount of this on earth if it were not being continuously generated as a disintegration product of uranium. The problem is to understand what peculiar sort of mechanism is responsible for the very wide differences in the actual life of different uranium atoms, and why the average life of radium atoms is so much shorter than that of uranium.

The theory of Gurney-Condon-Gamow showed that this strange behavior was one of the most remarkable consequences of the new wave mechanics, which had originally been developed to explain the motions of electrons in the outer part of the atom. It is a fundamental characteristic of wave motion that it can go a little way into regions where it ought not to go according to oversimplified theories. For example, in geometrical optics, if a ray of light is traveling through a block of glass and makes too great an angle with the normal to a glass-air interface, then when we calculate the direction which the ray should have on emerging into the air, it comes out imaginary. Physically the light is totally reflected, and there is no transmitted ray of light. But experiment shows that a little light does penetrate a short distance into the air, its intensity dying off exponentially to negligible values in a distance equal to one or two wavelengths of light. The same sort of thing happens when we put microwaves into a wave guide that is too small to give real transmission to the waves in question. Simple theory says the propagation of the wave is imaginary and this means that the wave is propagated a little distance, dying off exponentially in such a wave guide. Practical attenuators for microwaves are built on this principle, so there cannot be too much "long-haired science" about this idea.

This also applies in quantum mechanics to the motion of alpha particles in the nucleus of the uranium atom. According to classical mechanics, a particle cannot go into regions where its potential energy (if it were there) would be greater than its total energy. This would require its kinetic energy to be negative; hence, its momentum would have to be imaginary. But in wave mechanics, an imaginary momentum is associated with an imaginary propagation which means an exponentially damped wave rather than an oscillatory one.

If we now consider the motion of a particular alpha particle in relation to the other constituents of a uranium nucleus, we have to suppose that, when it is inside, it is held by special attractive nuclear forces that are responsible for the general stability of all nuclei. This is a spherical region about 10^{-12} cm in radius. There is reason to believe the alpha particles move back and forth in this region with a velocity

of the order of 10^8 cm per sec, averaging about 10^{20} oscillations per sec. If an alpha particle tries to leave, it finds itself drawn back in by the nuclear attractive forces. Said otherwise, it would have to go into a region of space where its potential energy would be greater than its total energy. The region where this is so is not very thick, however. Once the alpha particle is definitely outside the nucleus, the strong electrostatic repulsive forces between the like charges of the alpha particle and the rest of the nucleus greatly reduce the potential energy. This is shown schematically in Fig. 2.



If the alpha particle were governed by classical mechanics, it could not penetrate from the inner region, where its potential energy is less than its total energy, to the outer region where this is true. To do so, it would have to pass through a region where its momentum would be imaginary. In quantum mechanics, it has a slight probability of doing this because its behavior is governed by a wave that can penetrate this region even though it is exponentially attenuated in doing so.

The alpha particle oscillates up to the edge of the nucleus about 10^{20} times per sec. The chance of disintegration in a second (reciprocal of the mean life) is about 5×10^{-18}. Therefore the attenuation introduced by the potential wall around the nucleus must be about 10^{-38} or 380 decibels.

This theory had a striking initial success in that it was possible to make quite good quantitative estimates of the attenuation from reasonable hypotheses about the unknown law of force between the rest of the nucleus and the alpha particle. Moreover it made clear a previously puzzling empirical correlation, known as the Geiger-Nuttall relation, according to which those elements decaying rapidly are the ones that send off alpha particles of highest energy. Referring again to Fig. 2, we see that, if the alpha particle energy is higher, the attenuation region will be smaller and the rate of disintegration greater.

Developed late in 1928, this theory provided a great stimulus to the study of nuclear physics which up until that time was hardly more than a potential branch of physics. Aside from the way it served to clarify ideas about the nature of natural radioactive disintegration, it also soon served as a great stimulus to experimental work.

As early as 1919, Rutherford had succeeded in disintegrating nitrogen atoms by bombarding them with alpha particles. But the total yield of disintegrations was extremely small and the associated phenomena, therefore, were difficult to observe. This is due to the fact that when the nucleus of an atom is bombarded with another charged particle, the two repel each other. The force of mutual repulsion tends to bring their relative velocity to zero before the two colliding particles have got very close together. After that, the mutual repulsion causes them to fly apart again.

High Barrier Potential

It is natural to suppose that two such colliding particles must really come within a distance of about 10^{-13} cm in order for any real disintegration to take place. Looking at Fig. 2, we see that an alpha particle arriving from the outside would have to have an energy of at least 15 Mev in order to surmount the repulsive potential energy barrier representing the interaction of the alpha particle with the rest of the nucleus. Of course, this barrier is high because it is considered for uranium. For an element of $Z = 10$ instead of $Z = 92$, the height of the barrier is only about one ninth as great and lower voltages would be necessary.

But even considering the collision of the lightest elements, it appeared that it would be necessary to accelerate particles with a voltage in excess of 1,000,000 in order to get them to go over the barrier and penetrate the nucleus to produce artificial nuclear disintegration. In those days (before 1930), the cyclotron had not been invented nor were any large Van de Graaff electrostatic generators available. Yet it seemed that it was necessary to have voltages above 1,000,000 if a beam of protons was to be accelerated to sufficiently high energies to produce artificial disintegration. This view was completely altered when the concept of barrier leakage or the tunnel effect was applied to it. For, according to quantum mechanics, if a particle can leak out, it can also leak in, and therefore it is not necessary to have a voltage supply capable of accelerating the ions with enough energy to go over the top. This consideration encouraged Cockcroft and Walton to try to disintegrate lithium artificially by bombarding it with protons at unexpectedly low voltages.

This reaction can be written like a chemical reaction

$$_1H^1 + {}_3Li^7 \rightarrow {}_2He^4 + {}_2He^4$$

which means that when a proton (nucleus of hydrogen) collides with a lithium nucleus in the proper way the total material rearranges itself into two helium nuclei that fly apart. So well does barrier leakage work in this case that this reaction has actually been observed to occur with a bombarding voltage as low as 13 kilovolts.

High-voltage Accelerators

This result gave an immense impetus to the construction of high-voltage accelerators to obtain beams of hydrogen ions, deuterons, and helium ions of as great energy as possible. Soon afterward the discovery and development of the cyclotron made possible the rapid extension of investigation of nuclear reactions to a wide variety of substances. As one goes to heavier elements than lithium, higher voltages are needed because the potential barriers are higher but, in all cases, their effective height is considerably reduced by the potential barrier leakage.

The next great steps in the development of nuclear physics came in 1932 with the discovery of heavy hydrogen by Urey, Brickwedde, and Murphy, and the discovery of the *neutron* by Chadwick. The neutron is a particle (also governed by the laws of wave mechanics) which has a mass approximately equal to that of the proton, but has (hence its name) no electrical charge. These were found when beryllium and several other light elements were bombarded by alpha particles. Because they have no charge, they are quite penetrating and at first were confused with gamma rays. However, their behavior in many ways was soon found to be very different from that of gamma rays and all the observations were in accord with the idea that they were neutral particles of mass essentially the same as that of the proton.

Nucleus Constituents

Here at last was the answer to the question of what contributes the extra mass in complex atomic nuclei. As we have seen, the mass of most nuclei, A, is equal to or greater than twice the mass Z that comes from the protons it contains. It was now natural to assume that the nucleus was made up of two kinds of particles, protons and neutrons. The nucleus of mass A and charge Z consists of Z protons and $(A - Z)$ neutrons. That is the reason a plot of $A - Z$ against Z was chosen for Fig. 1. In terms of present views, the ordinate is the number of neutrons in the nucleus and the abscissa is the number of protons.

From this point of view, the nucleus of the atom of heavy hydrogen is especially interesting because it is the simplest possible compound nucleus. It consists of the simple binary compound of one proton and one nucleus. A full study of its properties is the most direct way to get information about the fundamental nuclear forces that bind a neutron and a proton. Such study is more fruitful than that of heavier

nuclei because of the greater mathematical complexity in analyzing the wave mechanics of the behavior of a nucleus containing more than two particles.

If a nucleus is to possess stability, it must be because some new kinds of specific forces come into play between neutrons and protons, between protons and protons, and between neutrons and neutrons, at distances of the order of 10^{-12} cm or less. Such forces overcome the repulsive effects due to the electrostatic interaction of the like charges on the protons. Naturally the study of these forces and their full description must be the foundation stone of basic nuclear physics in the same way that the inverse square law is the foundation stone of electrostatics. Attractive forces lead to negative potential energy; that is, the potential energy of two close particles is negative if it is reckoned from zero when the particles are at infinite separation. Thus it is necessary to do a positive amount of work in separating them against their mutual attraction. In the same way, the energy of a water molecule is negative compared to the energy of its constituents, two hydrogen atoms and one oxygen atom.

Energy Information

Information about the relative energies of different atomic nuclei can be obtained by studying the yields and thresholds of various nuclear reactions. For example, in the case of bombardment of lithium by protons, not only can one measure the energy of the protons which strike the lithium by measuring the voltage applied to the tube in which they are accelerated, but one can also measure the energy of motion of the two helium atoms formed. In ways like this, one can find that the two helium atoms have together more kinetic energy than the original kinetic energy of the bombarding proton.

From this, it follows that the neutrons and protons in two helium atoms must be in a state of lower total energy than when they are combined as in one lithium nucleus and a free proton. Determination of the energy changes in nuclear reactions in this way proceeds by identically the same kind of reasoning used in thermochemistry to get at the heats of formation of various chemical compounds by measurements based on heats of reaction of various reactions involving the compounds. To be sure, the experimental technique is different from that of classical calorimetry, but the basic idea is the same.

In the early 1930's, important developments of precision mass spectrometers were made. This was largely done by Bainbridge in this country. There are many kinds of mass spectrometers for special purposes. They are all devices in which a beam of positive ions is formed and made to pass through regions occupied by various electric and magnetic fields. The ions of different masses travel different paths. Sometimes the mass spectrometer is used as an analytical device to find out what material is present in the source by observing the masses of the ions produced. But the form of interest here is one that is adapted to the precise measurement of the magnitude of the individual atomic masses. In this way, it has been possible to determine many atomic masses to six-figure accuracy.

It has already been pointed out that the masses of the atoms are not accurately given by the integer A which we have associated with them on the scale that makes the O^{16} isotope have the arbitrarily assigned precise value of 16. But now we come to an even more extraordinary point. When the mass of the deuterium atom is measured precisely it is found to be 2.014725. Therefore, the mass of two deuterium atoms will be twice that number, or 4.029450. Now two deuterium atoms have just the makings of one helium atom, namely two outer electrons, two protons and two neutrons. Yet when the mass of the helium atom is precisely determined in the mass spectrograph it is found to be only 4.00386; in other words, in the process of forming helium from two deuterium atoms, there is a loss of 0.0259 units of mass which seem to have just disappeared. When the

accurate masses are used, many examples of the same sort of thing occur. To give another example, consider the formation of two helium atoms by the bombardment of lithium with a proton. The mass balance is

	INITIALLY		FINALLY
Li	7.01816	He	4.00386
H	1.00813	He	4.00386
	8.02629		8.00772

giving a loss of mass of 0.01857 units.

The mass is not really lost in cases like this. As long ago as 1905, Einstein was led by the theory of relativity to recognize that mass and energy are inseparably bound. They are two aspects of the same thing. It is not correct to say, as is sometimes done, that mass can be converted into energy or energy into mass. Mass *is* energy, and energy *is* mass. Wherever energy is, there is mass, but the experimental techniques by which a given quantity of mass-energy is recognized may sometimes be more like those involved in a mass determination and in other cases those in an energy determination.

Einstein showed that the amount of energy in ergs, E, associated with a mass M (grams) is given by

$$E = Mc^2$$

where $c = 3 \times 10^{10}$ cm/sec, the velocity of light. In atomic physics, one commonly measures mass on the scale in which unity is one sixteenth the mass of the O^{16} atom, which is 1.6604×10^{-24} gm. Energy is usually measured in terms of the electron volt, that is, the energy acquired by any particle possessing one atomic unit charge, like the electron or proton, when freely accelerated through a potential difference of one volt. Since the charge on the electron is 4.8×10^{-10} esu and there are 300 volts in one esu of potential, it follows that one electron volt is equal to 1.6×10^{-12} ergs. Therefore, the energy equivalent of mass in these units is expressed by the relation

one atomic mass unit = 932 Mev.

We are dealing in the examples cited with the "disappearance" of mass of the order of one or two hundredths of a mass unit—therefore a quantity of the order of several Mev. This corresponds in rough magnitude with the observed energies of the particles released in nuclear processes. Exact data on the energies gives exact check with the mass discrepancies, and for the past dozen years the Einstein relation has proved accurately valid on dozens of different nuclear reactions.

In this way, the measurement of precise masses of the atoms enables one to calculate in advance the energy release that accompanies any particular atomic process. It is possible, therefore, to estimate that the fission of the uranium atom will be associated with a release of about 200 Mev of energy per uranium atom split, since from the masses involved it is known that about one fourth of a mass unit disappears. Naturally this makes the precise measurement of atomic masses of the utmost importance in all matters concerned with atomic energy.

One of the questions which often perplexes the beginning student of nucleonics is this: Is the neutron a combination of a proton and an electron? There are some textbooks that say it is. Others will vouchsafe the opinion that a proton is a combination of a neutron with a positive electron. (The positive electron has not been mentioned in this article because, while such things exist, they seem only to have a transient existence and are not a permanent constituent of ordinary matter.)

Neutron Composition

The modern point of view on this is not entirely satisfactorily developed, but the ideas are quite different from those usually connoted by such a statement that a neutron "consists of" a proton and an electron in combination. Measurement of the mass of the neutron indicates a value of 1.00895 as compared with the mass of the hydrogen atom of 1.00813. The neutron thus has more energy than a hydrogen atom and could, so far as energy is concerned, spontaneously split into a proton and an electron, rushing apart with enough energy to account for the mass difference. Pos-

sibly free neutrons are unstable and radioactive in this way, but so far there is no experimental evidence for it.

The nearest thing we have to experimental evidence on changes of this kind is the study of both the natural and artificial beta particle emitting radioactive materials. A radioactive material which is beta-active is one that emits from its nucleus a high-speed electron (or positron). All of the artificially radioactive materials are beta-active substances. For these we do not have a simple barrier leakage theory like that applying to the emission of alpha particles from the heavy, naturally active alpha emitters such as uranium or radium. From the modern point of view, there are no electrons in the nucleus, *as such*, apart from what may be there on the hypothesis that a neutron is made of a proton and an electron in a peculiarly tight state of binding. But the hypothesis of this peculiarly tight state of binding is not very consistent with the fact that a neutron has more mass than a proton and an electron separately.

Energy Spectrum

The most remarkable thing about the beta-emitting radioactive materials is that, on disintegration, the different disintegrating atoms send out electrons of different energies. There is observed a continuous spectrum of emitted electron energies. This is true in spite of the fact that all of the atoms seem to be alike before and after disintegration. Therefore, there must be a definite energy difference between them.

In the case of the beta-active emitters, it is supposed that the true energy difference between parent and daughter substances corresponds to that carried away by the most energetic electrons emitted. The fact that in some disintegrations the electrons are emitted with a lesser amount of energy is formally accounted for by supposing that, really, there are two particles emitted: In addition to the emitted electron, there is supposed to be emitted a *neutrino* (Italian for little neutron, as in "bambino"). The emitted electron and the neutrino share the total energy between them in such a way that statistically, in some disintegrations, the electron gets all the energy. In most cases, however, it shares the energy in varying degrees with the other particle. The neutrino is postulated to have zero mass, or a mass considerably less than that of the electron and, having no charge, it completely escapes detection. Naturally this is not considered to be a very satisfactory way out, the neutrino having been invented for the purpose of balancing the books on the missing energy and having been postulated to have properties which make it almost, if not impossible, to detect. One of the most important fundamental discoveries that could be made in nuclear physics today would be some real evidence of the existence of the neutrino, or of its non-existence. Unsatisfactory as the neutrino idea may seem, it is the best that physics has had to offer for well over a decade.

Regarding the neutrino idea, however, one has to suppose that a neutron is capable of spontaneously changing into a proton with simultaneous emission of a proton and a neutrino:

$$N| \rightarrow P| + e + n$$

N is written for the neutron and P for the proton in this equation. But for the positron-emitting radioactive materials we have the opposite case in which a proton presumably changes itself spontaneously into a neutron and a positron and a neutrino,

$$P \rightarrow N + p + n$$

where p is the positron. It is necessary to suppose the emission of a neutrino occurs here for the same reason as before, namely to account for the continuous distribution in energy of the emitted positrons.

It must be confessed that the situation here is not satisfactorily understood, but it is clear that, because of the occurrence in nature of both positron- and electron-emitting radioactive materials, it is no more correct to suppose that the proton is a positron and a neutron than it is to suppose that a neutron is an electron and a proton.

Principles of Nuclear Particle Detection

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THE "FUNDAMENTAL" PARTICLES of physics may be listed as the "ordinary" negative electron, the positive electron (positron), the proton, the neutron, the positive and negative mesotrons (mesons), the neutral mesotron, the photon, and the neutrino. In ordinary matter, the protons, neutrons and electrons are the important constituents.

The present picture of the atom, which is quite well established, is that it consists of a compact central nucleus, roughly spherical in shape and with a radius of about 10^{-12} cm. The nucleus contains about 99.97% of the mass of the atom and is characterized by its (positive) charge or atomic number Z and its mass number A, where Z is measured in units of the electron's charge and A is the integer atomic weight on a scale where the main oxygen isotope has a weight of 16. This tiny massive central nucleus is surrounded by Z (negative) electrons which balance the nuclear charge. These electrons occupy definite "planetary" orbits about the nucleus such that the total atom "radius" is about 10^{-8} cm or 10,000 times the nucleus dimensions.

Isotopes and Isobars

Atoms with the same nuclear charge Z and different mass number A are known as *isotopes*. There are 272 known stable isotopes (*1*) ranging from one each for somewhat less than thirty elements to ten in the case of tin. Atoms with the same value of A but different Z are known as *isobars*.

The nucleus consists of neutrons and protons each of which have nearly unit atomic weight so the mass number A is an indication of the total number of neutrons plus protons in the nucleus. The neutrons have no charge and the protons each have a unit positive charge (in units of the electron's charge). The nucleus contains Z protons and $(A - Z)$ neutrons. The volume of the nucleus increases approximately linearly with the total number of particles, indicating that they pack somewhat like hard spheres or like the molecules in a drop of water. In fact, our present picture of nuclear dynamics is based on Bohr's "drop" model which extends the analogy of the drop of water in a detailed manner to the nucleus, subject to certain modifications required by quantum mechanics. The forces between nuclear particles are effective only for distances less than about 3×10^{-12} cm. Within this range, the force of attraction between nuclear particles is much greater than the coulomb repulsion, while for larger distances it decreases very rapidly to zero. Present theories of nuclear forces attempt to explain these forces as an "exchange" of mesotrons between the neutrons and protons. It is of interest that Yukawa postulated the existence of mesotrons for this purpose *before* they were experimentally discovered in cosmic rays.

In 1903, Einstein enunciated his celebrated theory of relativity from a consideration of results of the Michelson-Morley experiment which indicated the constancy of the velocity of light (in a vacuum) independent of the motion of the observer. Einstein's theory stated that a moving system has altered properties relative to a "stationary" system (either system may be taken as the "stationary" system). In particular, the moving system will shorten in the direction of its motion by the factor $\sqrt{1 - v^2/c^2}$, its clocks will run slower by the same factor, and the mass of any particle will increase

The primary applications of radioactivity involve only the physically well-understood "low-energy" nuclear reaction of a few million volts or less. This is the first of a series of articles which will be devoted to the principles underlying the design and use of radioactivity measuring instruments

by the factor $\frac{1}{\sqrt{1 - v^2/c^2}}$. Here v is the velocity of the moving system and c is the velocity of light in a vacuum. In particular, the mass increase $(m - m_0)$ times the square of the velocity of light is identified as the kinetic energy of a moving particle. By a general interpretation, the portion mc^2 is then understood to represent the *complete* relativistic energy of the particle and m_0c^2 its "rest" energy. This shows that there is a direct equivalence between mass and energy and, thus, it is possible to express energy in mass units. A basic energy unit in nuclear physics is the "mu" or mass unit and the "mmu" or millimass unit which equals 10^{-3} mu. One mass unit is the rest energy of a particle of unit atomic weight.

Electron Volt

Another energy unit of wide usage is the electron volt or "ev"

$$(1.602 \times 10^{-12} \text{ ergs})$$

which is the energy required to move a unit electronic charge through a potential difference of one volt. Similarly, "Kev" and "Mev" refer to kilo electron volts and million electron volts. Thus, a Van de Graaff electrostatic generator operating at 4,000,000 volts can give electrons, protons or deuterons a kinetic energy of 4 Mev or doubly charged helium nuclei 8 Mev.

One mass unit corresponds to 931 Mev or roughly 1 mmu $\approx$ 1 Mev. The self or rest energy of the proton on this scale is 938 Mev, that of the electron is 0.5 Mev, and that of the mesotron about 100 Mev.

The rest energy of the electron is small enough for the creation of an electron-positron pair from pure energy (gamma rays), an important mechanism for the absorption of gamma rays of energies well above 1 Mev. Conversely, when the positrons are stopped, each positron combines with an electron to give two "annihilation" gamma rays of total energy equal to the sum of the rest masses. Similar experiments on the creation of meson pairs and positive and negative proton pairs require, respectively, the several hundred Mev and the several billion ev energies of the future machines.

Binding Energy

The binding of neutrons and protons in nuclei may be compared with the binding of atoms to form molecules, with the difference that the binding energy per particle in the nucleus is about 10^7 times larger. The nuclear binding energy per particle averages about 8 Mev per particle which is about 1% of the rest mass of the particles. Thus, in the realm of nuclear physics, the relation $E = mc^2$ is foreseeably evident from the study of nuclear masses. Since the nucleus is composed of Z protons and $(A - Z)$ neutrons, the total mass of an atom should equal

$$1.00813Z + 1.00895(A - Z)$$

where 1.00813 and 1.00895 are the masses of the hydrogen atom and free neutron respectively. According to this calculation the total mass of an atom should be about 0.8% greater than the integer mass number A. Actually, the deviation from A is always much smaller than this, except for the lightest nuclei, and, for most nuclei, the deviation is a small negative amount.

The deviation of the true mass of an atom from the sum of the free masses of its constituents is called the *mass defect* and directly represents the total binding

energy of all the particles in the nucleus. It is thus an important quantity to know. In practice, another quantity called the "packing fraction" is also commonly used. It is defined as the ratio $\frac{M-A}{A}$, the difference between the true atomic mass and the mass number A divided by A. It represents the negative of the relative binding per particle as compared with O^{16}. When the packing fraction is plotted against A, it is found to be positive and irregular for the light elements. For $20 \leqq A \leqq 120$, it has a long, rather flat minimum near -6×10^{-4} mu, above which it rises smoothly to about $+6 \times 10^{-4}$ mu for U^{238}. The energy released when uranium fissions to give two nuclei of lower A is thus about 1 mmu per particle or about 200 Mev total energy. This represents the greater amount of binding energy per particle for the fragments.

Isotope Stability

If a chart of *stable* isotopes is examined, it will be found that for a given A, only a narrow range of values of Z are present. For the light elements, the greatest stability occurs when nearly equal numbers of neutrons and protons are present. For heavier elements, the coulomb repulsion of the protons becomes important and the region of greatest stability is shifted toward more neutrons than protons. The experimental stability curve, in fact, follows rather closely the theoretical relation (*1*)

$$Z = \frac{A}{2 + 0.0146A^{\frac{2}{3}}}.$$

As the value of Z is changed from its most stable value for a given value of A, the nucleus becomes less stable by an amount proportional to the square of the deviation of Z from its most stable value to Z_0.

A few of the other rules related to the relative stability of nuclei are also of interest. It is found that nuclei with an even number of both neutrons and protons are the most stable and most abundant in nature, there being 160 such nuclei out of the total of 272 stable nuclei. Nuclei with an odd number of both protons and neutrons (Z odd, A even) are generally unstable and only the four extremely light nuclei, H^2, Li^6, B^{10}, and N^{14}, are of this type. The nuclei with an even number of protons and odd number of neutrons (Z even, A odd), or the reverse (Z odd, A odd), are about equally stable and there are about 54 stable nuclei of each type.

Radioactivity

In general, of the natural isotopes, those below lead are stable, while those above lead are radioactive and are members of one of the three radioactive families (uranium, thorium and actinium). For these heavy nuclei, the coulomb repulsion of the protons is so large that greater total binding energy is obtained when the nucleus splits into two nuclei each of smaller mass. Thus, in principle, the heavier elements should all have split into lighter ones long ago. Although this process is energetically quite favorable, there are important inhibiting factors. Wood, for instance, does not burn spontaneously in air until it is heated to the ignition temperature. In the nuclear case, extra energy is needed to distort the nucleus by the amount needed to start the separation process even though large amounts of energy would be released if they separated a little farther. The required extra energy is more than the nucleus possesses so that the disintegration is forbidden by classical physics. The fact that the nucleus does disintegrate is due to the quantum mechanical process that permits a particle to "tunnel through" this "barrier" region, as first described by Gamow (*2*). The "barrier" refers to that interval of spacing from which the particle is classically excluded, as described above. However, the probability that this process will take place is very small. For example, in U^{238} an alpha particle (helium nucleus) is emitted from the nucleus with about 4 Mev kinetic energy. This process on the average requires about 6 billion years although

the alpha particle tries to escape about 10^{17} times a sec. Thus, about 10^{34} unsuccessful trials are required before the process is accomplished.

The probability that a given particle will penetrate the barrier in a given collision is determined by the Gamow factor. This is an exponential function of the charge and energy which gives a decreasingly small chance for the escape of any longer unit than an alpha particle from the natural radioactive nuclei. The probability is also very sensitive to energy of escape of the alpha particle. Thus, whereas U^{238} requires 4.56×10^9 years (half-life) to emit an alpha particle of 4.21 Mev, ThC' ($Z = 84$, $A = 212$) requires only about 10^{-7} sec (half-life) to emit an alpha particle of 8.947 Mev. The process of nuclear fission of the heavy elements into two almost equal fragments is more violent and requires a somewhat different analysis.

Isotope Disintegration

The second broad category of disintegration involves a change in the value of Z while A remains constant. Almost all artificial radioactive isotopes "disintegrate" by this process. In general, if a nucleus has a given mass number A and charge Z it may be more or less stable than the adjacent isobars of charge $(Z - 1)$ or $(Z + 1)$. If it is less stable, it usually is radioactive and will "decay" to the more stable neighboring arrangement. In the case in which the isotope with charge $(Z + 1)$ is more stable, it does this by converting a neutron into a proton. To accomplish this process, the nucleus emits a beta ray (negative electron) and a neutrino, although neither of these particles is normally present in the nucleus as a stable component.

The sum of the kinetic energies of the electron and the neutrino equals the difference in energy between the initial and final nuclei minus the energy (about 0.5 Mev) required to "create" the electron. The energy to "create" an electron need not be counted when atomic masses are used since the new atom contains an extra outer electron $(Z + 1)$. The rest mass of the neutrino is much less than that of an electron, and, since it has no charge, it does not interact with matter and cannot be directly detected. The principal effect of the neutrino is to carry away part of the available kinetic energy and conserve momentum. Whereas the alpha particles or gamma rays emitted in a radioactive disintegration have sharply defined energies corresponding to the transition, the beta-ray spectrum is a continuous one with all energies represented from zero to the maximum. This means that, when a given nucleus disintegrates, it emits only one electron but that the energy of this electron may lie anywhere between zero and the maximum value. Therefore, beta rays from a large number of similar nuclei will have all energies in this range represented.

Where the nucleus of charge $(Z - 1)$ is more stable, the nucleus will disintegrate by converting a proton to a neutron, accompanied, similarly, by the emission of a positron and a neutrino. This may also be accomplished by the process known as K-capture, L-capture, etc., where an orbital electron from the K or L electronic levels is captured by the nucleus. This latter process is particularly important when the energy difference between the initial and final nuclear forms is less than the self-energy (≈ 1 Mev) of a positron-electron pair. Since atomic masses are used, we consider both the creation of a positron and the fact that the final atom has one less atomic electron for positron emission. Capture of the more closely bound K electrons is much more probable than that of the L electrons (when energetically possible) and requires only that the difference in atomic masses (energies) be greater than the few Kev binding the orbital electron in the atom. In a few cases, where there is an odd number of both neutrons and protons present, the nucleus may be less stable than either of its neighbors so that both electron and positron and emission are observed. For example, Cu^{64} emits a β^- spectrum extending to 0.58 Mev *and* a β^+ spectrum extending to 0.66

Mev, and sometimes also decays by K–capture (3). The existence of more than one stable isobar with a given mass number A is explained by the fact that they are separated by less stable isobars. Thus, stable isobars differ by multiples of two in their Z values and have even values of A.

A nucleus with given charge Z and atomic mass number A may exist in its normal state (ground state) or in any of a number of excited "levels" or states. Nuclei with the same Z and A but different excitation energies are known as *isomers*. Usually, the excess energy is given off by the emission of a gamma ray (electromagnetic energy) in about 10^{-14} sec. In certain cases, the emission of a gamma ray is "forbidden" to some extent and the nucleus may require several seconds or longer to return to the ground state. If the nucleus is beta–active, it may decay by beta emission with a quite different half-life than it would if it were in its ground state. A characteristic isomeric transition process, known as "internal conversion," often occurs when the direct emission of a gamma ray is forbidden. This is a more complicated process in which an orbital electron is knocked out of the atom with a kinetic energy corresponding to the transition energy minus the binding energy of the electron. This is sometimes wrongly interpreted experimentally as a weak beta decay, although the nucleus retains the same values of Z and A after the transition.

Law of Radioactive Decay

Radioactive decay takes place according to purely statistical laws. If at time t there are N radioactive atoms of a given type present, then the number $-dN$ that will disintegrate during the interval dt is given by

$$-dN = \lambda N dt = \frac{1}{\tau} N dt$$

where $\lambda = 1/\tau$ is the "decay rate" and τ is the "mean life." If at $t = 0$ there are N_0 present, then

$$N = N_0 e^{-\tau t} = N_0 e^{-t/\lambda}$$

atoms will remain at time t. The half-life, $t_{\frac{1}{2}} = \tau \ln 2$, is the time required for N to decrease to half value. If radioactive nuclei are being produced at a constant rate R, the differential equation for the number present at any time is

$$\frac{dN}{dt} = (R - \lambda N)$$

which has the solution

$$N = R\tau - (R\tau - N_0)e^{-t/\tau}$$

showing an asymptotic approach to $N = R\tau$ for large values of the time. Artificial radioactive isotopes usually decay in one step to their final stable form, so that the above equations are adequate. The natural radioactive elements, on the other hand, decay in many successive disintegrations before reaching their final stable form. Thus, isotope No. 1 may decay to No. 2 which decays to No. 3, etc. If N_{01}, N_{02}, etc., are the number of atoms of each species initially present and they have decay constant λ_1, λ_2, λ_3, etc., then the differential equations are

$$\frac{dN_1}{dt} = -\lambda_1 N_1$$

$$\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2$$

$$\frac{dN_3}{dt} = \lambda_2 N_2 - \lambda_3 N_3, \text{ etc.,}$$

having as solutions

$$N_1 = N_{01} e^{-\lambda_1 t}$$

$$N_2 = N_{02} e^{-\lambda_2 t} + N_{01} \frac{\lambda_1}{\lambda_2 - \lambda_1} [e^{-\lambda_1 t} - e^{-\lambda_2 t}], \text{ etc.}$$

A case of special interest is the uranium series where U^{238} has a long half-life compared to the daughter products. When uranium is present in equilibrium with all of its decay products, the number of atoms of each type remains essentially constant so that the relative number of atoms of each type present is

proportional to the time τ each decaying atom remains, on the average, in that form. In particular, the "activity" or disintegrations per sec is the same for all of the members of the chain.

If a long-lived parent decays to a short-lived daughter, the two soon reach equilibrium where each has the same activity and decays at the rate of the parent. If a short-lived parent decays to a long-lived daughter product, the parent activity soon dies out and the daughter decays at its characteristic rate. The "activity" of the daughter is smaller than the initial activity of the parent in the ratio of the decay coefficients. The random nature of the actual disintegration processes and the factors involved in counting will be discussed more thoroughly later.

The half-life of a beta-active isotope is a sensitive function of energy of the transition. Theory indicates that the half-life should vary inversely as the fifth power of the energy. This is complicated by the fact that the transitions may be "allowed" types or be "forbidden" to various extents. In the latter case, they have a longer than expected half-life. Most beta activities have half-lives of between a few seconds to a few years with the region of 10^3 to 10^6 sec most favored.

Nuclear Reactions

When a stable nucleus is struck hard enough by a proton, deuteron, alpha particle, gamma ray, or fast or slow neutron, it is possible to convert it into some neighboring isotope that may or may not be stable. In general, this is the way in which artificial radioactive isotopes are produced. Artificial radioactivity was discovered as recently as 1933 by Curie and Joliot who observed that beta radioactivity was created when aluminum was bombarded with alpha particles from polonium. The intensity of the induced activity decayed with a 3-min half-life and the radioactivity was identified with phosphorus by chemical separations. The reaction they observed is usually stated as ${}_{13}Al^{27}(\alpha, n){}_{15}P^{30}$ which is read "aluminum, $Z = 13$, $A = 27$, has an alpha particle penetrating the nucleus with the emission of a neutron to form phosphorus, $Z = 15$, $A = 30$." The ${}_{15}P^{30}$ decays by the emission of positrons to form the stable nucleus ${}_{14}Si^{30}$. When an outside particle enters the nucleus a different "intermediate" nucleus is formed which, in the example, is ${}_{15}P^{31}$. The intermediate nucleus is generally in a highly excited state and will lose its extra energy by "boiling off" (drop model) a neutron, a proton, an alpha particle, or some more complicated groups of heavy particles or by the emission of a gamma ray. In general, it seems that almost any energetically permitted process can be made to occur with some probability if sufficient energy is supplied. Thus, the 200-Mev deuterons from the Berkeley 184-in. cyclotron have supplied sufficient energy to disintegrate O^{16} into four alpha particles, and 100-Mev X-rays from the 100-Mev betatron have produced such reactions as (γ, n), (γ, p), $(\gamma, 2n)$, (γ, np), (γ, α), $(\gamma, 2pn)$, $(\gamma, \alpha n)$ and $(\gamma, 2p3n)$ (*4*). In principle, if enough energy is supplied, very complex nuclear reactions should take place. From the practical point of view, however, in the preparation of radioactive isotopes using piles or approximately 8-Mev cyclotrons, most of the reactions mentioned are energetically forbidden or improbable. Very high-energy machines may provide moderate supplies of certain isotopes that cannot be produced readily or at all by other methods.

The following general statements may be made concerning the probability of various reactions for other than a few of the very light elements with anomalous packing fractions:

1. In general, about 5 Mev for $Z \approx 15$ to 12 Mev for $Z \approx 80$ are required for protons or deuterons to have a high probability of entering the nucleus or escaping from the nucleus against the coulomb repulsion barrier (see "natural radioactivity" above) and about twice this energy for alpha particles. The (d, p) reaction is a special case (Oppenheimer-Phillips process) since the deuteron (neutron + proton) is polarized by the nuclear field

and the process is similar to a capture of the neutron by the nucleus, and does not require the proton to penetrate the barrier.

2. When a proton or neutron enters the nucleus, the excitation energy of the intermediate nucleus is equal to the kinetic energy of the incident particle plus about 8 Mev binding energy. Removing a proton or neutron requires about 8 Mev to overcome the binding effect. In addition, in the case of the proton, extra kinetic energy is needed to penetrate the potential barrier.

3. Since there is no barrier repulsion for a neutron, slow neutrons can readily enter the nucleus. The probability for the capture of a slow neutron varies greatly from element to element and shows pronounced "resonance" effects as a function of the energy of the slow neutron. The width of these resonances is usually less than 1 ev and is small compared to their spacing. In general, when a slow neutron is added, the approximately 8-Mev binding energy is given up by the emission of a series of gamma rays of several Mev. Since A is increased to $(A + 1)$ while Z remains fixed, the position of greatest stability usually is obtained by β^- decay to $(Z + 1)$. Probably the majority of the radioactive isotopes available from piles are produced by slow neutron activation of samples radiated in the pile. Although a large number of isotopes are produced in enormous intensities as products of the fission process, it is rather difficult to recover these safely and to assure chemical purity.

4. Usually (n, p), (d, p), (d, n), (d, α), (p, α), (n, α) reactions require approx. 5 to 12 Mev kinetic energy and (α, n), (α, p) reactions about twice this. $(n, 2n)$ reactions require about 10 Mev, (γ, n) reactions about 8 Mev, and (γ, p) and (γ, α) reactions over 12 Mev, depending on Z.

5. An energy balance for nuclear reactions may be written just as for chemical reactions. The energy released in a reaction is known as the "Q" of the reaction. For example, we may write:

$$_4Be^9 + {}_1H^2 \rightarrow {}_5B^{10} + {}_0n^1 + Q$$

where $Q = 4.20$ Mev $= 4.51$ mmu. If Q is negative, an energy at least as great as this threshold value must be supplied for the reaction to take place at all. It may be noted that the reaction given in the above example is the one used with cyclotrons to obtain a maximum yield of fast neutrons.

An isotope chart should be consulted for specific information concerning radioactive isotopes (*1*) (*3*) (*5*) (*6*).

Detection of Radioactivity

The detection of radioactivity, where alpha rays, beta rays, gamma rays or neutrons are emitted, is made possible through the interaction of these radiations with matter. In contrast, the neutrino has not been directly detected because of its lack of interaction. Essentially, all devices for the detection of the nuclear particles respond to the primary or secondary ionization produced when a rapidly moving charged particle passes through matter. In the case of alpha rays and beta rays, this ionization is directly produced in the slowing down and stopping of these particles themselves. Gamma rays are detected by the ionization produced by the photoelectrons, Compton recoil electrons, and electron-positron pairs that they produce as the mechanism of their interaction with matter. Fast neutrons are detected by the ionization produced by the "knock on" nuclei resulting from their billiard-ball-like collision with the nuclei of the matter they traverse. Slow neutrons are detected through the action of the radiation resulting from their absorption.

In general, slow neutron detectors may be placed in three categories. The first are the ionization chambers, proportional counters, etc., used to detect the ionizing heavy particles resulting from (n, α) reactions or (n, p) reactions. The most important slow neutron detector is boron which has a strong capture probability for slow neutrons, and which disintegrates within less than 10^{-10} sec by the emission of an alpha particle and the release of about 2.75 Mev in kinetic energy. The reaction is

$_5B^{10}$ (n, α) $_3Li^7$, and the alpha particle and recoil $_3Li^7$ nucleus together form about 70,000 ion pairs in the region near the point of capture. Lithium has also been frequently used as a slow neutron detector since it has a large capture probability (about $\frac{1}{10}$ that of boron) for the reaction

$$_3Li^7 + {}_0N^1 \rightarrow {}_1H^3 + {}_2He^4$$

with the release of about 4.7 Mev as kinetic energy for the recoil $_1H^3$ and $_2He^4$ fragments. A third spectacular detection method of the first type is the use of slow neutron fissionable material such as U^{235}. The 200-Mev energy released in fission produces short, heavily ionized tracks containing about 5×10^6 ion pairs.

Slow Neutron Absorption

The second type of slow neutron detector uses a slow neutron absorbing material such as Cd and detects the neutron through the action of the energetic gamma rays given off as the excited nucleus loses the approximately 8-Mev binding energy of the neutron. The third type of slow neutron detector, in contrast with the instantaneous action of the first two types, utilizes the production of a beta activity in a detector such as Au, Mn, Ag, Rh, In, Dy, etc. The amount of the induced beta activity is later measured and is taken as an indication of the slow neutron intensity at the time of the experiment. Fast-neutron detectors of this type are sometimes used when a simple detector is desired that will respond only to neutrons of energy above a certain "threshold" energy (7).

Detection of nuclear particles ultimately is accomplished through the observation of the effects of the ionization produced in stopping fast-charged particles—mainly alpha particles and electrons. This subject and that of the detection instruments will be discussed in greater detail in the following articles of this series.

The slowing down of rapidly moving charged particles is due to the coulomb interaction of the particles and the atomic electrons of the traversed matter. In passing an atom, the particle imparts an impulse (force $\times$ time) to the electrons. The magnitude of this impulse will be proportional to the particle charge and, roughly, inversely proportional to its velocity. If the velocity imparted to the electron is proportional to the impulse, then the kinetic energy is porportional to the square of the impulse. This energy given to the electron causes ionization and represents a loss of kinetic energy by the charged particle. The loss of kintic energy per unit distance traversed is thus roughly proportional to (a) the density of the traversed matter, (b) the *square* of the particle charge, and (c) the *inverse* square of the particle velocity. It is found that approximately one ion pair is produced in air for every 35-ev loss of kinetic energy, nearly independent of the intensity of ionization along the path. By this rule, the total number of ion pairs formed per ionizing particle may be calculated. The density of ionization along the particle track is widely different for alpha particles and electrons. For electrons with kinetic energy T greater than the self-energy (0.5 Mev) of the electron, the velocity of the electron is very nearly equal to c, the velocity of light. The relativistic equation for the ratio of a particle's velocity to that of light, v/c, in terms of its kinetic energy T and its "rest energy" $E_0 = m_0c^2$, is

$$\frac{v}{c} = \sqrt{\frac{(E_0 + T)^2 - E_0^2}{(E_0 + T)^2}} = \sqrt{1 - \frac{1}{(1 + T/E_0)^2}}$$

For an alpha particle of 4-Mev kinetic energy and rest energy $E_0 = 3740$ Mev, the velocity is about $\frac{1}{20}c$. From the above considerations, a 4-Mev alpha particle should have about

$$(2)^2 \times (20)^2 = 1600$$

times as much the ionization per unit path length as a fast electron.

Alpha particle tracks are distinguished as short, straight, heavily ionized tracks of definite range. The length of the path in air is about 1 cm

for 2 Mev, 2 cm for 3.4 Mev and 5 cm for 6.3 Mev. This corresponds to an energy loss of over 1 Mev per cm of air or about 40,000 ion pairs per cm.

Energetic electrons (beta rays) have much larger ranges than alpha particles. Their tracks also differ from those of alpha particles by the irregularity of their tracks. Since the slowing down is essentially by interaction with atomic electrons of the same mass, the electron frequently is deflected through large angles and its motion through matter is somewhat similar to a diffusion process. The straightened-out length of path (or range) of electrons in air is about 1 cm for 25 Kev, 10 cm for 90 Kev, 1 meter for 0.4 Mev, and 10 meters for 2.4 Mev. The ratio of the range in air to that in aluminum is such that 1 mm of aluminum is equivalent to about 180 cm of air.

The considerations for monoenergetic electrons must be greatly modified when the beta radiation from a radioactive material is considered, since the spectrum of beta rays contains all energies from zero to the maximum value E_{max}. By an accidental combination of circumstances, the absorption of natural beta rays is very nearly exponential with thickness of material traversed, *i.e.*, $I \approx I_0 e^{-x/x_0}$ where x_0 is the thickness to reduce the intensity to $1/e$ of its original value. The value of x_0 is between about $\frac{1}{5}$ and $\frac{1}{10}$ of the maximum range of electrons with energy E_{max}. The "half absorption thickness" is about 0.1 mm of Al for $E_{max} = 0.5$ Mev, and 0.4 mm for $E_{max} = 2$ Mev.

Gamma rays are electromagnetic radiation (called photons or quanta) similar in nature to light, heat radiation, radiowaves and X-rays. In fact, gamma rays and X-rays even have the same range of energies, the distinction between the two being in the method of their production. The term "gamma rays" is applied to those photons which are emitted from nuclei during a nuclear transition from a more excited state to a less excited state. Gamma rays thus are characterized by sharply defined energy values. The term X-rays is applied to the same type of photons when they are produced by external electrons. When fast electrons are slowed down in matter, such as in the target of an X-ray tube, the sudden de-accelerations resulting from close collisions with electrons and nuclei cause the emission of electromagnetic radiation of energy ranging from zero to the full energy of the electron. This is known as the "continuous X-ray spectra." When a bound electron is knocked out of an atom, a more loosely bound electron will "jump down" to fill the vacant orbit, and "characteristic" X-radiation of energy equal to the energy of the electronic transition is liberated. This is called K, L, etc., radiation according to the orbit position of the ejected electron. The energy of a photon is related to its wave length λ and its frequency f by the relations $E = hf$ and $\lambda f = c$, where h is Planck's constant (6.624×10^{-27} erg-sec) and c is the velocity of light.

Photons are absorbed through their interaction with electrons by the photoelectric effect, the Compton effect, and, when energetically possible, by the formation of electron-positron pairs. In the photoelectric effect, the energy of the photon is transferred to a bound electron in an atom (usually a K electron), and the electron leaves the atom with a kinetic energy equal to the difference between the photon energy and its binding energy. Characteristic X-radiation is subsequently emitted by the struck atom. The Compton effect may be expressed as a relativistic "billiard ball" collision between an electron at rest and the photon which has not zero "rest mass" but an "energy mass" $mc^2 = E$, and which moves with the velocity c before and after the collision. In general, the photon is scattered through some angle with a loss of energy to the electron.

If a monoenergetic (monochromatic) beam of gamma rays is incident on an absorbing material, the intensity of the photons which have *not* interacted with the matter will decrease exponentially with the thickness traversed. The absorber "thickness" is usually ex-

pressed in cm or in gm/cm². The expression of thicknesses in gm/cm² is a more uniform practice since it takes into account the actual mass of material traversed. It is numerically equal to the product of the volume density (gm/cm³) and the thickness. The transmission law may be expressed $I = I_0 e^{-\mu x} = I_0 e^{-x/x_0}$ where I_0 and I are the initial intensity and the intensity after traversing the thickness x (in cm or gm/cm²), μ is the "absorption coefficient" in cm⁻¹ or cm²/gm, and x_0 is the "mean absorption thickness" in cm or gm/c². For photons of a few Mev energy, the primary absorption is almost entirely due to the Compton effect, and the mass absorption coefficient is nearly independent of the energy and of the nature of the material traversed. This coefficient is numerically somewhat less than $\frac{1}{15}$ cm²/gm and corresponds to a "mean absorption thickness" $x_0 = 15$ to 40 gm/cm². The absorption coefficient increases rapidly for energies below 1 Mev due partly to the increased magnitude of the Compton effect but mainly to the rapidly increasing importance of the photoelectric absorption. This will be discussed in more detail in the next article.

Detection Devices

The devices for the detection of nuclear radiation may be briefly listed and defined as follows:

1. Scintillation Method. If a screen coated with a fluorescent material, such as ZnS, is exposed to alpha rays, a tiny flash of light can be seen each time an alpha particle strikes the screen. With this method, the eyes must first be "dark adapted" and the screen viewed under a low power microscope. Much of the early research in nuclear physics was conducted using this simple method of detection. It has the disadvantage of being tedious and tiring, subject to human error and fatigue effects, and unsuited to rapid counting. Recently, this method has been improved by the use of photomultiplier tubes and "counting circuits."

2. Photographic Method. The photographic plate was the first radioactivity detection device used. When photographic plates are exposed to alpha rays or protons, short, dense tracks are observed which can be studied through a microscope. Recent developments in producing special, thicker emulsions and in techniques for three-dimensional measuring of tracks have promoted the usefulness of this method. The fine results on neutron-proton scattering by Chadwick and Powell were obtained using this technique. The photographic method is particularly useful in cosmic-ray investigations. Because of its cumulative properties, even the most rare phenomena may be recorded by this method. Photographic plates also respond to beta rays and gamma rays. They are widely used in health physics as monitors to be carried by persons exposed to radioactivity as a test for overexposure.

3. Cloud Chamber Method. The most direct visual evidence on the detailed kinetics of nuclear reactions is obtained from the use of cloud chambers. When a gas saturated with any vapor is suddenly expanded in volume adiabatically, there is a decrease in temperature and the vapor becomes supersaturated. The formation of droplets does not then occur generally throughout the volume, but only on certain "condensation centers" such as dust particles or, of importance for this use, on ions in the gas. If the gas is expanded at very nearly the same time that an ionizing event occurs within the gas volume, droplets will form at the position of each ion in the gas and the "path" of the particle may then be viewed or photographed directly. If a magnetic field is present, the curvature of the track indicates the momentum of the particle, and the density of ionization (droplets) gives other important information. In a collision or multiple disintegration process, the trajectories of the incident particle and product particles may be seen and detailed measurements made.

4. Ionization Chamber Methods. An ionization chamber may be defined as a system in which a gas volume is defined by two (or more) bounding

electrodes which are maintained at a difference of potential. When ionizing particles traverse the chamber and produce ion pairs, the positive charges are attracted to the negative electrode and the negative charges to the positive electrode. (The chamber may be regarded as a condenser which "leaks" an amount of charge or current corresponding to the number of ion pairs collected.) Electroscopes and electrometers are electrostatic potential-measuring devices that indicate the degree of charge of the ionization chamber. Changes in reading are related to the integrated effect of the intensity of ionization in the chamber. Special vacuum tubes have been constructed and electrometer circuits designed for use in connection with ionization chambers to measure ionization currents even much lower than 10^{-15} amperes. These devices are capable of great sensitivity and precision, and may be used to measure intensities varying by more than a factor of 10^8 in magnitude. They are used to detect all types of radiation, except when used as direct current devices, in which case, they cannot distinguish between various types of radiation.

When one electrode of the ionization chamber is connected to a high-gain vacuum-tube pulse amplifier and provision is made to restore the potential through a recharging resistor, the resulting system may be used for the detection of individual particles, since "bursts" of ionization occur only at the instants when ionizing particles traverse the chamber volume. The size of a pulse is accurately proportional to the number of ion pairs produced in the chamber by the particle. Since fast electrons only lose part of their energy in traversing the chamber, while short-range, heavily ionizing particles (such as alpha particles) may have their full range in the chamber, it is possible to count the heavily ionizing particles and ignore a large "background" of less ionizing particles.

By calibrating the pulse height against particle energy, it is also possible to count selectively only those particles having a narrow range of energies. It is through this method, for example, that Dunning and many others since have been able to observe the huge 200-Mev fission pulses extending 20 times higher than the uranium alpha particle pulse (themselves many times larger than the beta ray and noise background) when U^{235} is exposed to slow neutrons. A boron- or lithium-lined ionization chamber or one filled with BF_3 gas is a most important device for "counting" slow neutrons. The slow neutrons are absorbed by the B or Li nuclei by the reactions $B^{10}(n, \alpha)_3Li^7$ or $_3Li^7(n, \alpha)_1H^3$ in which the heavy ionization produced by the disintegration particles is observed. To illustrate the orders of magnitude involved, fission produces about 5×10^6 ion pairs of 1.6×10^{-19} coulombs charge each. This corresponds to approximately 10^{-12} coulombs per fission. If the amplifier circuit has approximately 20-mmf input capacitance, a pulse of approximately 0.05 volts input to the amplifier is obtained.

The ionization chamber method is also used to "count" fast neutrons through effects of the recoil nuclei produced during collisions.

5. Proportional Counter Method (*8*). When the ionization chamber is constructed using a concentric cylinder arrangement for the electrodes and sufficient voltage is applied between the electrodes, it is possible to obtain much larger pulses when detecting ionizing radiation. A typical proportional counter for slow neutron detection uses an outer cylindrical cathode 5 cm in diameter and 20 cm long, surrounding an axial wire anode 0.1 mm in diameter and filled with BF_3 gas at 30 cm pressure. Below about 2,200 volts, the counter operates as an ionization chamber, giving normal small pulses due to the collection of positive ions at the cathode and electrons at the central wire. As the voltage is raised, however, the size of the pulses increases continuously until the Geiger counter region is reached (as is discussed below).

This increase in pulse size is caused by the additional ionization produced in the gas by the electrons in the region of intense electric-field strength near the central wire.

The "gas multiplication factor" will increase from unity at low voltages to 1,000 or larger at increased voltages. If the voltage is not made too high, the output pulses will still be proportional to the initial ionization, and differentiation of the pulses due to different types of particles may be obtained. The proportional counters have an advantage over ionization chambers in that less expensive, less sensitive amplifiers may be used. Thus, for example, amplifier noise and microphonic troubles largely disappear when proportional counters are used. Their disadvantages include the need for more careful construction and high voltage stabilization.

6. Geiger Counters. If the voltage across a proportional counter is gradually increased, a point will finally be reached where a discharge extending along the full length of the central wire will be produced independent of the magnitude of the initial ionization. The discharge automatically extinguishes itself in properly filled "fast" counters while large-value series resistors or "extinguishing circuits" must be used for "slow" counters. Geiger counters are characterized by the fact that their pulses are relatively large and are independent of the nature of the primary ionizing particle. They are very widely used as detection instruments and have great sensitivity since they count every ionizing particle that passes through them. They have the disadvantage, relative to ionization chambers and proportional counters, that different types of radiations cannot be directly distinguished.

7. Crystal and Cerenkov Radiation Counters. Experiments have recently begun on the development of these two new types of counter device. To describe them briefly: The crystal counter consists of a slab of suitable crystalline material between two electrodes across which a high voltage is maintained. When an ionizing particle traverses a portion of the crystal, it is found that ionization pulses are produced at the electrodes, probably by the excitation of electrons to "conduction" levels in the crystal by the ionizing particle. Crystal counters have the theoretical advantage over ionization chambers in that they have a very much greater sensitive mass of material in which the ionization may be produced.

If a rapidly moving charged particle traverses a dielectric optical material (such as lucite) at a velocity greater than the velocity of light ($= c/\text{index}$ of refraction in the material), the electromagnetic field of the charged particle experiences difficulties in establishing itself. This may be compared with the difficulties in flying an airplane at velocities greater than that of sound. In particular, energy is lost to a "bow wave." This "Cerenkov" radiation contains visual frequencies and may be focused on a photomultiplier tube and counted. Such emission of radiation was first observed by Cerenkov (*9*). Its theory has been developed by Frank and Tamm (*10*) and by E. Fermi (*11*). Recently the Cerenkov radiation has been utilized to count electrons generated in lead by X-rays from a 20-Mev betatron (*12*).

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Isotope Techniques in Biochemistry—I

Few chapters in biochemistry have been unaffected by the use of isotopes. Many problems, beset with contradictory data, have been clarified by a few clear-cut experiments with tracer elements. Application of isotope techniques to previously unexplorable fields of research, has been even more fruitful. This is the first of a series of articles on the subject

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UNTIL VERY RECENTLY, isotopes supplies were very limited, in variety, quantity, and concentration, and few researchers had the funds or technical background necessary for the prosecution of tracer research. Now, however, stable isotopes in high concentration and the instruments for the quantitative determinations are commercially available at prices within the budget of many laboratories. The difficult problems of instrument operation and maintenance have been somewhat eased by improvements in design. The most important change, though, as every biochemist knows, has come from the application of atomic piles to the production of an impressive variety of useful radioactive isotopes, in large quantities and at relatively low prices. The situation now permits almost everyone to "get into the act."

The research biochemist who plans to enter the field of tracer research should first recognize that the use of an isotope is not a cure-all. All but the simplest of tracer methods are complex and require painstaking planning, literature searching, and, frequently, development of synthetic, isolation, and measurement procedures. A general self-immersion in the nature of isotope techniques is highly advisable so that the researcher can review the blank spaces in his field with the "isotopic attitude." These articles are devoted to the various types of problems that can be attacked with the tool of isotope labeling.

The fundamental principle of tracer methodology is the assumption that ordinary chemical and physical processes do not distinguish between the various isotopes of an element. With special apparatus, however, the relative abundances of the different isotopes or the presence of radioactive isotopes can be readily determined. The "tagging" of metabolites is hardly new, the classical work of Knoop with omega-phenyl fatty acids perhaps being the best known. Unfortunately, the 2-carbon fatty acid oxidation scheme that arose from this work suffered from uncertainty due to the presence of the "unphysiological" phenyl group. Isotopes, on the other hand, permit the closest approach to a natural tag that one could hope for. It is this naturalness that has made isotopic labeling so powerful a technique.

Availability Limitations

Isotopes of practically every element in the periodic table can be obtained more or less readily (*1*). The stable isotopes of general biochemical interest are H^2 (deuterium), N^{15}, C^{13}, O^{18}, B^{11}, S^{34}, and Fe^{58}. The last five are not very readily obtainable, especially in high concentrations, but increased demand will no doubt result in an increased supply.* With the exception

* Eastman Kodak can supply heavy nitrogen as $N^{15}H_4NO_3$ or potassium phthalimide and C^{13} as sodium cyanide. The availability of these and other isotopes is discussed elsewhere in this issue of NUCLEONICS.

of oxygen and nitrogen, radioactive isotopes are available for all elements of value in biochemical work. They fall roughly into two categories, those with weak and those with strong radiation. The weak group includes: H^3, C^{14}, S^{35}, Ca^{45}, Fe^{59}, Co^{60}; the strong group includes: C^{11}, P^{32}, Na^{24}, K^{42}, Cl^{36}, Br^{82}, I^{131}, Cu^{64}. Some isotopes, such as Fe^{55}, are best obtained from cyclotrons. Cyclotrons in the researcher's locality are particularly necessary for the preparation of the short-lived radioelements.

Analytical Considerations

A description of the methods of measurement of isotopes is beyond the scope of this paper, but consideration of the limitations of the methods is essential in planning experiments, and a brief discussion will be presented here. The stable isotopes exist in nature in varying degrees of abundance (see table), and measurements consist of determining the ratio of abundance of the two or three most common isotopes of the element in question. With normal nitrogen, for example, the ratio of N^{15} to N^{14} is 38/9962; in other words, 38 out of every 10,000 nitrogen atoms are N^{15}. The ratio is more conveniently expressed as "atom per cent," which in this case is 0.38. The expression "atom percent N^{15} excess" has been introduced by Rittenberg and Schoenheimer (*2*) to ease calculation of dilutions. An enriched sample might contain, say, 2.00 atom percent N^{15}; atom % excess is calculated by subtracting the normal abundance, which gives 1.62 atom % excess. The usefulness of this expression is indicated by the following example: Suppose 1 mole of a nitrogen-containing compound, whose N^{15} content has been raised to 2.00 atom %, is mixed with 9 moles of the same compound having only the normal N^{15} content of 0.38 atom %. The resultant N^{15} concentration is $[(1 \times 2.00) + (9 \times 0.38)]$ /10 or 0.54 atom %. This is 0.54 − 0.38 or 0.16 atom % excess. If the atom % excess of the original enriched sample (1.62) had been used for the calculation, the recognition that the sample had been diluted 10 times would have given the correct answer immediately: 1.62/10, or 0.16 atom % excess. When the molecular weight of the compound being studied has been appreciably increased by the presence of the heavy isotope, a slight correction must be made (*3*).

Stable Isotopes Existing in Nature

Element	*Isotope masses*	*Abundance ratios*
H	1:2	99.98:0.02
B	10:11	18.4:81.6
C	12:13	98.9:1.1
N	14:15	99.62:0.38
O	16:17:18	99.76:0.041:0.20
S	32:33:34	95.1:0.74:4.2
Ca	40	96.96
	42	0.64
	43	0.15
	44	2.06
	46	0.0033
	48	0.19
Fe	54	6.04
	56	91.57
	57	2.11
	58	0.28

The precision and sensitivity of isotope concentration measurements depend on the type and design of the instrument used. The only practical method for the stable isotopes is the mass spectrometer, although other devices have certain advantages for deuterium. In general, the ratio of abundance can be determined within a probable error of 1% down to 0.2%, depending on the element and the absolute value. In the low ranges, the absolute sensitivity is in the vicinity of 0.004 atom %. The sample size required for analysis is quite small, being of the order of 50 microatoms of the element. Advances in the field of isotope determination are being made at a rapid rate now, and these figures should not be considered final.

Although the analytical methods will pick up an increase of about 0.004 atom % above the normal isotope abundance, it is advisable to plan experiments so that small values like

these need not be considered significant. First of all, contamination of reagents to a slight degree is extremely difficult to avoid; this tends to be cumulative. Contamination of a 5-mg sample of ammonia with only one microgram of 30% N^{15} ammonia will raise the N^{15} value by

$$(30 \times 0.000001)/0.005$$

or 0.006 atom %. Second of all, the purity of a sample isolated from an organism or mixture that contained some high-concentration material can rarely be so high that no high-concentration material at all is present. Thirdly, the normal atom % value is not a constant, and varies slightly according to the source. The basic principle of tracer work, the assumption of equal treatment of isotopes, is not strictly true. Very slight differences in reaction velocities exist; indeed, it is these differences that permit the preparation of samples enriched above normal.

Nitrogen-15 Abundance

Analyses of the N^{15} abundance in normal amino acids isolated from animals have been made (*2*), and the atom % excess values (compared with air) range up to 0.010%, averaging around 0.004%. A similar study of the abundance of K^{41} in various anatomical parts gave values of 6.55 to 6.80 atom % (*4*). An increase in the reliability of very low analytical data can be obtained by running parallel controls and several independent samples, as well as by applying more rigid purity criteria. Some of the above considerations apply even more severely to work with radioelements, which tend to be obtained in tremendous activities and can therefore contaminate samples more seriously.

Radioactive isotopes of biochemical interest occur in nature in negligible amounts or are entirely absent.* The equivalent of the normal atom % found with the stable isotopes does exist, however, due to the universal distribution of some radioactivity and cosmic-ray radiation. This background activity, therefore, has to be subtracted from the observed activity and serves to limit the precision of measurements on weakly active samples. The magnitude of the background varies with each instrument, a common value being 50 counts per minute, or the equivalent.

Measurement Problems

A number of additional complications exist in radioactivity measurements, particularly when one uses elements having a low-energy radiation. The use of a Geiger-Müller tube with a window (so that the sample is outside the tube) results in loss of a certain fraction of the radiation by absorption in the window and by self-absorption. The latter is due to absorption in that part of the sample that is between the disintegrating atom and the G-M tube. The consequence of this effect is that an increase in the weight of the sample does not increase the observed activity proportionately, so that it is not possible to determine values of the *specific* activity (activity per gram of sample) below a certain minimum. Almost all window G-M tubes are placed on only one side of the sample, a factor resulting in the loss of much activity. At least half the radiation goes in the other direction. It is apparent from these considerations alone that measurement of the *absolute* activity requires the estimation of several correction factors, making high precision difficult. Fortunately for the biochemist, the actual activity is frequently of no interest and relative activities serve quite well. Using some of the original labeled material, it is necessary to prepare a set of diluted standards and, from these, prepare a calibration curve of calculated versus observed activities. All samples must be prepared and measured in a very uniform way, however, to give good comparative results.

Some of the difficulties peculiar to window G-M tubes are obviated by the use of G-M tubes filled with the sample itself or by the use of ionization chambers, but other shortcomings in the generally available instruments tend to negate the advantages as far as pre-

* C^{14} exists in many places as the result of cosmic ray-induced transmutation of N^{14} (*5*).

cision is concerned. In the case of tritium, however, the weakness of its radiation prevents the use of window tubes. A complete discussion of the problems of radioactivity measurement, particularly for each of the different elements, cannot be presented here and the reader is referred to the recent monograph by Kamen (*6*) and the current literature (*7*).

Counts Required

In general, a sample should give a reading at least equal to the background reading. This means that enough radioactive atoms must be present to register at least 50 disintegrations (counts) per minute. For C^{14}, which has a rather weak radiation, the absolute activity would have to be 50 to 100 times the measured activity, using a commercial thin-window G-M counter and a sample containing one mg of carbon (as $BaCO_3$). The precision obtained at this low activity would be around 5% if a fairly lengthy time were devoted to the determination.* Greater sensitivity and precision have been claimed for C^{14} analyses by the use of an ionization chamber (*8*). With somewhat more active samples, higher counting precision can be obtained, and the problems of uniform preparation of samples and stability of the instrument tend to become the limiting factors. Few methods have been developed, however, that give results with a precision better than 2%. Radioactivity instrumentation is a rapidly developing field so that the warning on mass spectrometry precision given above applies here as well.

Actually, the minimum requirements for radioactivity analysis given above are rather modest, since the raw materials available from the Oak Ridge pile contain relatively huge specific activities. C^{14}, for instance, is supplied in units of about 0.8 millimoles (as $BaCO_3$) containing an activity of 1 millicurie (about 2.2×10^9 cpm). This sample can be diluted about 1,000,000 times to give 350 pounds of $BaCO_3$ whose activity is still easily detectable. Most biochemical isotope problems so far have involved much lower dilutions, on the order of 100 times. While future work seems destined to involve larger dilutions, it does not seem likely that more than a small fraction of experiments will require dilutions greater than 1,000 or 10,000 fold. When isolations of pure compounds are necessary, as in most cases, the purity of the samples becomes the limiting factor, since very few procedures can lower impurities below 1% or 0.1%. The presence of 1/10,000 of the activity of the original material in an isolated substance cannot always be safely considered as arising from the isolated substance itself.

Metabolism Interference

While the high specific activity of the raw materials permits working with quite active samples and thereby obtaining accurate measurements, the factor of interference with metabolism acts in the opposite direction. Too high an activity, because of the disintegrating effects of nuclear radiation, will interfere with the organism or enzymes being studied. Therefore, a minimum activity is desirable. The exact balance cannot be stated here since few experimenters have investigated this problem. Furthermore, data from previous experiments with X-rays or different radioelements cannot be applied readily to any new problem because of differences in distribution and the nature and intensity of the radiation. Even data obtained with another compound of the same element are likely to be useless, since few compounds are distributed in an organism in the same way. The best assurance that the radioactivity level being used is not interfering with the biological system is obtained by using two somewhat different levels of activity in parallel experiments and then comparing the results. Most workers operate with quite low activities and sacrifice precision.

These and other considerations will

* Improved precision is available on G-M counters by taking readings for a longer period of time, thereby reducing the statistical variations in emission and background.

be brought up under the discussions of the general types of isotope problems.

A general classification scheme of biochemical problems susceptible to the isotope approach, roughly in order of increasing complexity, follows:

1. The locational problems: *Where* in the system is the labeled substance, and how long did it take to get there?
2. Reaction mechanism studies.
3. Analytical problems, qualitative and quantitative.
4. Metabolic problems: Into what has the labeled substance been converted?

This listing is essentially for didactic convenience and should not be construed as contradicting the fact that many experiments combining several of the above aspects have been performed.

Locational Problems

Just about the simplest isotope experiment that can be performed is the introduction of a labeled substance into one part of a system and the subsequent determination of where it has gone. In this way, problems in absorption, excretion, permeability, rate of diffusion, rate of transfer of solutes and solids, rate of liquid flow and other fields can be clarified enormously. Illustration of these and other types of isotope researches will have to be kept to an unsatisfying minimum because of the already voluminous number of papers.

When the radioelements having penetrating radiation are employed the distribution can be followed simply by placing a G-M tube near the subject. The dramatic concentration of iodine by the thyroid gland was demonstrated in this manner (*9*). For greater locational discrimination, a lead shield can be placed around most of the detector tube. This technique seems best adapted to work with humans. It should be recalled, in planning this type of experiment, that the radiation from radioelements goes out in all directions, so that concentration in the thicker parts of the body results in ambiguous activity measurements.

The absorption or circulation of labeled substances can be followed in human beings either by having the subject hold the G-M tube in his hand, or, in the case of the isotopes with weak radiations, by inserting a tiny G-M tube into a blood vessel (*10*). The former technique was used by Hamilton (*11*) to follow the uptake of ingested radiosodium, potassium, chlorine, bromine, and iodine. In a similar manner the rate of blood circulation has been studied (*12*) and sites for amputation of limbs with impaired circulation indicated (*13*). If it is desired to follow a compound that occurs in very small concentrations in the blood, in which case even a penetrating tag will lose too high a proportion of its counts by skin absorption, the use of the micro G-M tube seems advisable.

The use of stable isotopes or those having weak radiation for locational work requires special treatment of the organism. Samples of known weight must be removed from various parts and then prepared for analysis, usually by an ashing or combustion procedure. Even more refined localization data can be obtained by fractionating the tissues before analysis. Indeed, dilution by the non-isotopic tissue material may make this necessary in order to get a sample of measurable concentration, even in the case of strong emitters. Fractionation is often very simple. If a mineral element is being studied, ashing will remove much radiation-absorbing material. If a fat-soluble vitamin tagged with C^{14} is being traced, ether extracts of the tissue samples can be made. Ninhydrin decarboxylations (for amino acids) or other specific decomposition reactions can be used. Of course, a specific precipitant, together with added carrier material if necessary, is an ideal method of fractionation.

Radioautograph Production

Another type of localization technique, especially useful for quasi-microscopic work, is the production of radioautographs. As the record of the discovery of radioactivity reminds us, photographic films can be fogged by the radiations from radioactive ele-

ments, and if a thin section of tissue is placed on a suitable film for a time and the film subsequently developed, fairly accurate localization can be obtained. In this way, the distribution of labeled substances in plants and animals has been studied, particularly the movement of nutrients inside plants (*14*). Although all the radiographic work published so far has been done with the strongly-radiating elements, it has been demonstrated recently that C^{14} is also suitable for this technique (*15*).

A refinement of the earlier radioautograph techniques is the method developed at the National Institute of Health (*16*). This method permits locating alpha-particle emitters with great precision by affixing and staining the tissues slices directly on the photographic plate. Perhaps the method can be adapted to the class of beta emitters, which includes practically all the elements of interest to biochemists.

The locational techniques mentioned so far give very limited data, especially if no fractionation is performed. The mere presence of a compound does not tell us whether it is being stored there or is being metabolized or incorporated into the cell proper. The presence of a compound in small quantities in a certain tissue does not preclude its being in high concentration in a small fraction of the tissue. The nature of the combination of the tracer element is totally unknown, unless it is known that the original compound is not converted.

Intracellular Distribution Study

An interesting technique suitable for the study of the intracellular distribution of isotopes, stable and radioactive, is that developed by Claude at Rockefeller Institute (*17*). By breaking the cell walls of a tissue in a gentle manner and centrifuging at different speeds, one can separate the different parts of a cell in bulk and thereby obtain sufficient material for any isotopic analysis. Nuclei, secretory granules, chromatin strands, chloroplasts and other parts can be separated rather cleanly. Little application to tracer work has been made so far (*18*), but increased use may be expected.

"The way to be prepared for enemies in a possible future war is to be ahead of them in every department; and the way to be ahead of them is to have more, cleverer, and better-informed men working harder, on the basis of more thoroughly diffused scientific information."

. . . *Louis N. Ridenour*, Fortune, *November*, 1945

The use of isotope labeling for locational work sometimes serves as a convenient substitute for other methods of analysis. When an unnatural, nonmetabolized substance is being studied, it is frequently easier to synthesize it with (preferably) some strong emitter and get the relative distribution with a G-M counter. This has been done recently with 2-iodo-3-nitrobenzoic acid, a plant growth inhibitor (*19*). Even if some metabolic conversion does take place, as long as the breakdown products are not produced too quickly, spread too widely, or incorporated into other compounds, the data should be of some usefulness.

The elegance of the tracer approach is demonstrated particularly in its application to permeability problems, where transfer across a membrane can be studied even when the concentrations on both sides of the membrane remain practically unchanged. For instance (*20*), when radioactive sodium chloride (Na^{24}) was injected into dogs in an amount that left the plasma concentration relatively unchanged, the rapid transfer of Na into the red cells could be demonstrated. The rate of transfer apparently followed simple diffusion law.

The nature of placental permeability has been investigated with isotopes by a number of workers. The studies of water transfer made by Gellhorn and Flexner (*21*) illustrate some of the

considerations necessary in this type of work. Heavy water was injected into a pregnant guinea pig and after ten minutes the fetuses were removed by Caesarean section and the deuterium concentrations of fetal and maternal blood determined. It had previously been found (*22*) that a ten-minute wait was ample to permit equilibration of the heavy water with the maternal extravascular water. Moreover, the rate of transfer of water to the fetuses was shown to be rather constant for the first ten minutes. Knowing the total fetal body water (found by vacuum distillation) and the deuterium concentrations of maternal and fetal blood, one can calculate how much water had been transferred across the placenta.

Calculation Considerations

The calculation is based on the following considerations: if the infinitesimal volume of water transferred, dV_T, has a deuterium concentration of D_T, the differential amount of deuterium transferred is $D_T dV_T$. This equilibrates very rapidly with the fetal water, whose volume is V_F, producing water with a deuterium concentration greater by $dD_F = D_T dV_T / V_F$. (Simultaneously, an equal differential amount of water is transferred from the fetuses to keep their total volume constant.) Integration of the differential equation gives the working equation:

$$V_T = V_F \frac{D_F}{D_T}$$

where V_T and D_F are the values obtained after 10 minutes. The value of D_T used was not the one obtained from the maternal blood after ten minutes, but a corrected one. This was necessary because the maternal blood deuterium concentration is not a constant (as was assumed in the derivation) and drops rapidly during the first few minutes after injection while the blood water equilibrates with the maternal extravascular fluid. The use of differential equations of this sort is found not infrequently in isotope literature, particularly in kinetic metabolism studies.

Similar to permeability experiments are those made on gastro-intestinal absorption and excretion. The mere presence of a substance in feces does not indicate whether it is there because it was incompletely absorbed or because some has been excreted. Similarly, one cannot tell in the normal animal whether the body level of a given substance is maintained by adjustment of the rate of absorption or rate of excretion. These problems are grist for the isotope mill.

An interesting example of this approach is that furnished by Schoenheimer, Rittenberg, Shapiro, and Koster (*23*) with the aid of deuterium. The well-known phenomenon of high fecal fat content in cases of bile deficiency had previously been interpreted as indicating that fat absorption cannot occur in the absence of bile. When, however, the glycerides of deuterium labeled fatty acids were fed to humans with bile fistulae (with the bile deflected outward), the fat isolated from the feces was found to contain a deuterium concentration only about one third of the original. Since the amount of fat found was about equal to that fed, two thirds of the ingested fat must have been absorbed—despite the bile deficiency—and an equal amount of unlabeled fat must have been *excreted* by the intestine.

Bacteria Causes Uncertainty

The presence of intestinal bacteria provides a degree of uncertainty in any type of experiment that involves the intestine (*24*). Especially when small effects are observed, it is desirable to check the results by injection of the isotopic compound or by the use of an intestinal antiseptic (sulfasuxidine or sulfaguanidine) or by an entirely different approach. Another attitude, however, is that which considers the intestinal flora, which may be rather uniform within a species, as part of the normal, "complete" animal. This is not too unworkable an attitude particularly if its dangers are kept in mind.

The fat problem described above required the isolation of the substance

ingested, but in the case of substances that normally occur in the gastrointestinal tract in tracer quantities, such as most minerals and vitamins, or are absorbed only to a very small degree, it is advisable to examine the other side of the wall or to use radioactive isotopes. The use of stable isotopes frequently requires the isolation of a pure compound, or else a very specific decomposition reaction, and also calls for a quantitative analysis of the feces or the tissue from which it was isolated. When radioactive isotopes are used, all that is necessary in many experiments is the determination of the activity of an aliquot. If the specific activity is too low, or metabolic conversion is suspected, then an extra purification step is necessary. If, for instance, the absorption of Vitamin E were being studied, labeling with C^{14} might well give the answer. One might feed one milligram of material, having a total activity of 100,000 counts per minute (cpm), and then collect the feces for the next 24 hours. To raise the specific activity of the excretions, the unsaponifiable fat fraction could be extracted and an aliquot examined for activity. If $\frac{1}{10}$ of the extract gave a reading of 100 cpm, the total excreta must have had an activity of 1000 cpm, indicating that all but 1% of the ingested dose had been absorbed. To eliminate errors from differences in specific activity, the activity of the *original* material should be determined under similar conditions, that is, by the addition of 1 microgram to an equal amount of the unsaponifiable fat fraction from normal feces.

Iron Useful

Very interesting and revealing data have already been obtained by techniques of this sort, iron perhaps having been the most useful. It has been demonstrated, for instance, that normal animals absorb and excrete very little iron, in contrast to the rather dynamic situation with most foods. This means that the body re-utilizes the iron derived from broken-down red cells, although the porphyrin moiety has been shown to be excreted. The storage of iron in ferritin, the effects of cobalt and anemias on absorption, and other problems in iron metabolism have been considerably clarified by the use of radioactive iron (*25*).

Very complex substances and even living cells can be labeled and traced in their careers through other organisms. The distribution and breakdown of foreign proteins and red cells can be followed by feeding one organism on isotopic food, isolating the desired material, and injecting or feeding this to another organism (*26,27*). Glycine containing N^{15} is admirable for labeling red cells (*28*), although radioactive iron or phosphate can be used (*29*). Microorganisms can readily be grown on isotopic media, and then, after thorough washing to remove contaminating isotopic material, introduced into the experimental animal. Labeled plasma proteins have been prepared by feeding dogs lysine labeled in the ϵ-amino group with N^{15} (*30*). A locational study with polypeptides prepared from yeast grown on an N^{15} medium indicated that mice may concentrate them in the skin (*31*).

Use of Proper Label

A point that must be considered in this type of experiment, as in many tracer experiments, is that a label should be used that will not be lost too readily, and thereby appear in the general metabolic pool of the host. The deuterium on oxygen, nitrogen, sulfur and activated carbons is lost by exchange with water almost instantly. Deuterium and N^{15} might be lost from bacteria at too rapid a rate, owing to oxidation-reduction reactions and deaminations. Inorganic ions are probably inadvisable, although the iron in red cells does not exchange with plasma iron. An interesting example of the use of a slowly exchanging label is that involving phosphate-labeled red cells (*32*). Some red cells were withdrawn from a pregnant woman, suspended in radiophosphate until a certain amount of phosphate exchange had occurred, washed free of inorganic material, and

then resuspended in plasma and injected back into the same woman shortly before parturition. Fetal blood (from the umbilical cord) was then examined and found, in one of the cases studied, to contain appreciable radioactivity in the red cells. Although some phosphate in the maternal red cells had exchanged with plasma phosphate and had been picked up by the fetus, this could not explain the amount of active phosphorus in the fetal cells, since fetal and maternal plasma phosphate were too low in activity. The conclusion drawn, then, was that a certain amount of leakage of red cells through the placenta had taken place.

The availability of labeled proteins will probably be of great value in immunological problems (*26*). The preparation of isotopic pure antigens or antibodies should permit clarification of the problems of antigen-antibody combination.

Study with Radiobromine

An unusual type of locational study has been made with radiobromine (*33*), in which advantage was taken of the fact that dibromotrypan blue, an azo dye, is selectively concentrated by lesions and inflamed areas. Experiments with rabbits suffering from internal abscesses showed that some of these areas could be picked up fairly well with a Geiger counter, masked with a lead case and passed over the skin. It should be remembered that highly penetrating isotopes must be used, and also that concentrations deep in the body cannot be located very exactly since the radiation goes outward in all directions. Nevertheless, if very specifically concentrating substances can be found, some of the difficulties of medical diagnosis will be eased considerably. Similar work has been done with P^{32} and breast tumors.

A few specific concentrators are known now, and, as is well known, have been used not only for diagnostic work but for the treatment of hyperactive tissues. Iodine, which is concentrated very efficiently by the thyroid gland, has been used in the treatment of hyperthyroidism (*34*) and a type of adenocarcinoma (*35*). The high concentration of radioactive material acts to destroy some of the tissue, in a manner similar to the action of X-rays. In general, any unusually active tissue will tend to take up metabolites faster than the normal tissues, so that an ingested dose of radioactive metabolite will concentrate in that tissue and destroy it. Radiophosphorus has been used by many workers rather successfully in this way for polycythemia vera and certain leukemias. The difference in concentration abilities of abnormal and normal tissues is unfortunately quite small, so that careful dosing is necessary to avoid damage to normal tissue. In this type of work, short-lived isotopes are preferable to the long-lived ones, so that treatment can be restricted to a fairly definite time. For this reason, I^{130} (12.6-hour half-life) has been used in preference to I^{131} (8-day half-life). There is still great need, however, for a search for substances more specifically absorbed by cancerous tissues as well as pathogenic microorganisms. The intriguing possibility of modifying genetic structure by feeding people or dosing sperms with radioactive substances specifically taken up by chromosomes or genes is not too remote.

Isolation Procedures

Another application of locational tracer techniques is in the development of isolation procedures. Just as enzyme isolation methods are tested at each step by activity measurements, so can one add some pure isotopic material to the mixture being worked up and then determine the activity of the various fractionation products (*36*). For the reasons outlined in the discussion of intestinal absorption, radioactive labels are preferable to stable ones. The determination of partition coefficients, so useful in liquid-liquid separation techniques (*37*), is made quite simple if a small amount of the substance of interest is prepared with a tracer element and its distribution determined. The high activity of

radioactive labels permits the addition of so small an amount that the nature of the system remains normal.

The application of isotope techniques to reaction mechanism, analytical and metabolic problems will be taken up in later papers, as well as a discussion of the synthetic problems peculiar to isotope work.

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Elements Renamed

Elements with atomic numbers 43, 85 and 87, have received new names from their discoverers. *Technetium* is the new designation for 43, *astatine* for 85, and *francium* for 87. These titles were announced at a recent meeting of the American Chemical Society. Element 61 is the only element yet unnamed.

Quantum Mechanics for Nuclear Technology—I

Much more than mathematical models and procedures for study of sub-atomic processes is available through quantum mechanics—it provides a new insight into matter and energy. New ideas and mathematical techniques involved, with some of the important applications in nucleonic physics, will be described in a series of articles of which this is the first

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QUANTUM THEORY was proposed in 1900 by Max Planck as a new approach to the very old search for the general laws governing motion of matter. A quarter of a century later, quantum mechanics was invented almost simultaneously by Werner Heisenberg and Erwin Schroedinger. Since then, this new mechanics has grown to be an everyday tool for physicists and physical chemists.

Now that an understanding of nucleonic phenomena is becoming increasingly necessary in engineering and the life sciences, mastery of the fundamentals of quantum mechanics will be valuable to workers in these fields as well. This discipline serves as a key to complete understanding of most of the literature of nucleonic physics, even in its experimental and applied phases.

First to be emphasized is that many basic and "obvious" concepts of classical physics, offered in Newtonian mechanics, physical optics and electromagnetic theory, cease to have meaning when applied to problems whose physical dimensions are those of the molecule and atom (about 10^{-8} cm) or smaller. The approach provided by quantum mechanics, judged by its results, is applicable to atomic problems and also to nuclear problems (except for explaining the structure of elementary particles such as neutrons, protons, and electrons). Most of the success so far achieved in describing the phenomena of nucleonic physics has been obtained through the application of quantum-mechanical principles.

Such things as the scattering and absorption cross sections, so vital in pile operation, must be interpreted quantum-mechanically. Many of the most elementary processes, such as alpha decay, cannot be understood at all without quantum mechanics. Why certain processes have certain lifetimes, why some elements become radioactive and therefore are unsuitable for energy transfer from power piles, what selection rules forbid certain transitions which would be allowed on purely energetic considerations—all these phenomena require quantum mechanics for thorough understanding. As a final example, the explanation of nuclear fission, as formulated by Bohr and Wheeler,* is based on the quantization of the states of motion of the nucleus on the model of a liquid drop.

Fundamental Principles

Although the mathematics may require careful study, basic ideas and postulates of quantum mechanics are few and comparatively simple.

1. The first, and perhaps the most important, is the operational† attitude. This attitude regards a physical system as being in a certain state at a certain time only so far as that result would be given by an actual measurement (observation) of it. For instance, we

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* Bohr and Wheeler, *Phys. Rev.* (1939).

† P. W. Bridgeman, "The Logic of Modern Physics," The Macmillan Co., New York, 1927.

cannot assume, as the classical physicist did, that at a certain time an electron has known position and velocity, without considering the results of an experiment to determine these quantities. Such an assumption, in fact, gives incorrect results, because, in making the measurement, we would change the condition of the electron, *i.e.*, its position, velocity, etc.

2. In particular, measurements are subject to the following limitations:

Matter has both wave and particle characteristics, each picture being limited in its applications. The classical particle (Newtonian mass point) picture holds until the Heisenberg uncertainty limitation becomes important. This principle can be stated thus:

$$\Delta p_x \cdot \Delta x \geq h, \qquad \Delta t \cdot \Delta E > h \quad (1)$$

We cannot know ("know" here is used in the operational sense, as signifying the result of an experiment) both the position x and the momentum in the x direction p_x of a system, or its energy E and the time t at which the system possesses that energy, to an accuracy greater than these relations allow (h stands for Planck's constant, 6.61×10^{-27} erg-sec). This is so because, in accurately measuring one of these conjugate quantities (p and x, or E and t are said to be "conjugate" to one another), we change the other by an uncertain amount, the uncertainty being large enough to result in the Heisenberg relations.

3. Radiation has the same properties, with the additional relation that the energy of the particles of radiation, known as *quanta*, is given by $E = h\nu$ where ν is the frequency of the radiation and h is Planck's constant as before.

4. Quantum mechanics must be interpreted statistically. On any given measurement of the position of a quantum, for instance, we cannot say *a priori* what the result will be, but the wave picture gives us an idea of what the distribution of positions will be in a large number of measurements under identical circumstances. The same thing applies to particles. Thus, if our mathematical solution to a problem shows a neutron has a probability of one-half of being in a certain region, it means that a large number of experiments would show the neutron as being in that region in one-half of the experiments. What has happened is that the measurement has "forced" the neutron into the region under consideration exactly half of the time, but we cannot say beforehand on which tests that will occur.

5. Diffraction experiments with particles show not only that matter has wave properties, but that

$$\hbar\mathbf{k} = \mathbf{p},$$

where $\mathbf{k}$ has the magnitude $2\pi/\lambda$ and a direction the same as the direction of the propagation of the wave,

λ is the wavelength characteristic of the waves associated with the moving particle,

$\mathbf{p}$ is the momentum of the particle and

$\hbar$ represents $h/2\pi$.

Vectors are in **boldface** type.

This is the result we would expect if the matter and radiation waves have similar properties, because, for radiation, the momentum is given classically by $p = E/c$ and $E = h\nu$. Thus $p = \frac{h\nu}{c} = \frac{h}{\lambda}$. The definition of $\hbar$ and $\mathbf{k}$ then gives $\mathbf{p} = \hbar\mathbf{k}$. If the angular frequency of these "De Broglie" waves is $\omega = 2\pi\nu$, we would also expect by analogy with quanta that the energy of the particle (excluding the rest energy mc^2, as this is a nonrelativistic theory) is $E = \hbar\omega$. These two equations

$$\mathbf{p} = \hbar\mathbf{k} \quad (2)$$

$$E = \hbar\omega \quad (3)$$

give us the relation between the characteristics of the particle and those of the corresponding wave.

Schroedinger Time-dependent Equations

A plane wave can be expressed by

$$\psi(\mathbf{r}, t) = Ae^{i(\mathbf{kr}-\omega t)} \quad (4)$$

where $\mathbf{r}$ is the position vector. We

want to find the differential equation of which this is the solution. Taking space and time derivatives, we find that

$$\frac{\partial \psi}{\partial x} = ik_x\psi,$$

$$\frac{\partial^2 \psi}{\partial x^2} = -k_x^2\psi, \text{ etc.}$$

$$\nabla^2\psi = \frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2}$$

$$= (k_x^2 + k_y^2 + k_z^2)\psi$$

$$= -k^2\psi \qquad (5)$$

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

(the Laplacian)

$$\frac{\partial \psi}{\partial t} = -i\omega\psi \qquad (6)$$

$$\text{Therefore } \psi = -\frac{\nabla^2\psi}{k^2} = -\frac{1}{i\omega}\frac{\partial \psi}{\partial t} \qquad (7)$$

Since for a free particle of mass m

$$E = \frac{p^2}{2m} \quad \text{and} \quad \mathbf{p} = \hbar\mathbf{k},$$

$$E = \frac{\hbar^2 k^2}{2m}.$$

But also $E = \hbar\omega$

$$\text{so} \qquad \hbar\omega = \frac{\hbar^2 k^2}{2m} \qquad (8)$$

Substituting in (7),

$$-\frac{1}{i\frac{\hbar^2 k^2}{2m\hbar}}\frac{\partial \psi}{\partial t} + \frac{\nabla^2\psi}{k^2} = 0$$

$$-\frac{\hbar}{i}\frac{\partial \psi}{\partial t} + \frac{\hbar^2}{2m}\nabla^2\psi = 0 \qquad (9)$$

Equation (9) is the time-dependent Schroedinger equation for a free particle of mass m. Any wave can be expressed as a sum of plane waves and, as the equation applies to each term in the sum independently of $\mathbf{k}$ and ω, it applies to the sum as a whole and thus to the most general wave representing the particle in any state. By applying proper boundary conditions to this equation, we can find the solution for any problem.

EDITOR'S NOTE: The differential equations used in classical physics and engineering to describe the "states" of a system are defined by the value of the system's coordinates and the momenta of its constituent particles. However, the derivation of the Schroedinger equation, carried out here, assumes that the most exact description possible for our knowledge of the state of a system is contained in the specification of a corresponding function ψ of the coordinates and time. This wave function for matter waves determines the relative probability of different positions for each value of the time t.

Since $\frac{\hbar}{i}\frac{\partial \psi}{\partial x} = \frac{\hbar}{i}k_x i\psi = p_x\psi$, $\left(\frac{\hbar}{i}\frac{\partial}{\partial x}\right)$ acting on any wave function has the same effect as p_x. Therefore, the operator $\left(\frac{\hbar}{i}\frac{\partial}{\partial x}\right)$ can profitably be thought of as giving p_x. We denote this by

$$\frac{\hbar}{i}\frac{\partial}{\partial x} \rightarrow p_x; \qquad \frac{\hbar}{i}\frac{\partial}{\partial y} \rightarrow p_y; \qquad \frac{\hbar}{i}\frac{\partial}{\partial z} \rightarrow p_z$$

Thus $$\frac{\hbar}{i}\text{grad} \rightarrow \mathbf{p} \qquad (10)$$

Also $$-\frac{\hbar}{i}\frac{\partial \psi}{\partial t} = -\frac{\hbar}{i}(i\omega)\psi = E\psi$$

so $$-\frac{\hbar}{i}\frac{\partial}{\partial t} \rightarrow E \qquad (11)$$

Where there is a force acting on the particle, we represent it by $\mathbf{F} = -\text{grad } V$, where V is a potential function. In this case, we replace E in (9) by $E - V$, E being the total energy and $E - V$ the kinetic energy. This gives

$$-\frac{\hbar}{i}\frac{\partial \psi}{\partial t} + \left[\frac{\hbar^2}{2m}\nabla^2 - V(\mathbf{r})\right]\psi = 0 \qquad (12)$$

Since $\frac{\hbar^2}{2m}\nabla$ stands for $-\frac{p^2}{2m}$, then $\frac{\hbar^2}{2m}\nabla^2 - V(\mathbf{r})$ stands for $-(T + V)$.

In classical mechanics, for a particle in a field $\mathbf{F} = -\text{grad } V$, $T + V$ equals the "Hamiltonian" function H, which in this case equals the total energy.

Thus (12) is commonly written

$$\frac{\hbar}{i}\frac{\partial \psi}{\partial t} + H\psi = 0 \qquad (13)$$

where H is a function of coordinates, momenta, and time,

$$H\left(\frac{\hbar}{i}\frac{\partial}{\partial x}, \ldots x, \ldots t\right)$$

Before proceeding to specific instances, we should try to attach a more physical meaning to the wave frequency ψ. ψ by itself has no direct physical meaning, but the quantity

$$P = \psi^*\psi = |\psi|^2 \qquad (14)$$

(ψ^* stands for the complex conjugate of ψ, a complex number)

represents the "probability density." By this, we mean $\psi^*\psi dxdydz$ is the probability of finding the particle in question in a given region of dimensions dx, dy, and dz at time t. As noted before, this has only a statistical meaning. A given measurement will show the particle either in the region or not in it, but a large number of measurements, under identical circumstances, will show the particle as being in the region in a fraction $Pdxdydz$ of the determinations. As the probability of finding the particle somewhere in space is 1 at any time t, $\int\psi^*\psi dxdydz$, the integral taken over all space, is 1. This provides a condition, known as *normalization*, on ψ. Though ψ need not be finite everywhere, it must be quadratically integrable, that is $\int\psi^*\psi d\mathbf{r}$ must be finite over any portion of space. ($d\mathbf{r}$ means $dxdydz$).

Another physically meaningful quantity is $\mathbf{i}$, the "current density," which must satisfy, with P, a continuity equation similar to that of hydrodynamics. The equation is

$$\text{div } \mathbf{i} + \frac{\partial P}{\partial t} = 0 \qquad (15)$$

where $\text{div } \mathbf{i} = \frac{\partial i_x}{\partial x} + \frac{\partial i_y}{\partial y} + \frac{\partial i_z}{\partial z}$.

This gives, using (12), $\mathbf{i} = \frac{\hbar}{2mi}[\psi^* \text{ grad } \psi - (\text{grad } \psi^*)\psi]$. $i_x dydzdt$ is the probability that, during the time dt, the particle passes through an area $dydz$ in the positive x direction minus the probability that it passes through in the negative x direction. Various conditions are also attached to $\mathbf{i}$. For instance, there can be no "sources" or "sinks" of probability, so the integral of the normal component of $\mathbf{i}$ over any closed surface must vanish.

Various velocities are associated with a wave. There is $\mathbf{u}$, the phase velocity, which tells how quickly the phase of a disturbance travels in space.

Fig. 1 shows the graph of the real part of the wave function $\psi = Ae^{i(\mathbf{kr}-\omega t)}$ as a function of x (assumed to be the direction of propagation). The equation of the surfaces of constant phase, phase being defined by $\delta = \mathbf{kr} - \omega t$ is

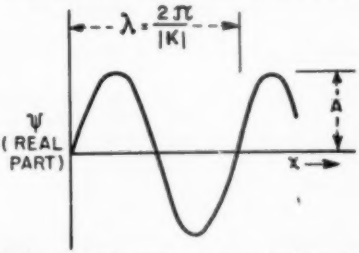


FIG. 1. Real part of $\psi = Ae^{i(\mathbf{k}\cdot\mathbf{r}-\omega t)}$ as a function of x.

$$\mathbf{kr} - \omega t = \text{const} \qquad (16)$$

These surfaces move, as can be seen from (16), with velocity

$$\mathbf{u} = \frac{\omega}{|\mathbf{k}|} \qquad (17)$$

in the direction of $\mathbf{k}$. This velocity is not the one physically observable, except when it is the same as the group velocity.

The group velocity is defined by the vector $\mathbf{v}$, with components $\frac{\partial\omega}{\partial k_x}, \frac{\partial\omega}{\partial k_y}$ and $\frac{\partial\omega}{\partial k_z}$. Its meaning can be seen from the following. Suppose that there are two waves of frequency ω_1, ω_2 and wave vector $\mathbf{k}_1$, $\mathbf{k}_2$, respectively. These two waves are given by $\psi_1 = A_1e^{i(\mathbf{k}_1\mathbf{r}-\omega_1 t)}$ and $\psi_2 = A_2e^{i(\mathbf{k}_2\mathbf{r}-\omega_2 t)}$. Their sum is thus $\psi = A_1e^{i(\mathbf{k}_1\mathbf{r}-\omega_1 t)} + A_2e^{i(\mathbf{k}_2\mathbf{r}-\omega_2 t)}$.

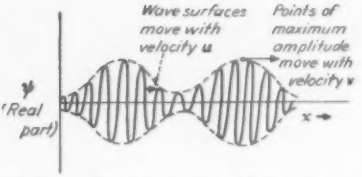


FIG. 2. Sum of two waves showing phase and group velocity.

The points of the same amplitude (Fig. 2) are given by $(\mathbf{k}_2 \cdot \mathbf{r} - \omega_2 t) - (\mathbf{k}_1 \cdot \mathbf{r} - \omega_1 t) = \text{const}$, that is $(\mathbf{k}_2 - \mathbf{k}_1) \cdot \mathbf{r} - (\omega_2 - \omega_1)t = \text{const}$. Their velocity $\mathbf{v} = \frac{d\mathbf{r}}{dt}$ is given by $\Delta\mathbf{k} \cdot d\mathbf{r} - \Delta\omega dt = 0$, where $\Delta\mathbf{k} = \mathbf{k}_2 - \mathbf{k}_1$ and $\Delta\omega = \omega_2 - \omega_1$. This gives $\Delta k_x v_x + \Delta k_y v_y + \Delta k_z v_z = \Delta\omega$. Since this holds for arbitrary $\Delta\mathbf{k}$, $v_x = \frac{\Delta\omega}{\Delta k_x}$, etc., or

$$v_x = \frac{\partial\omega}{\partial k_x}, \quad v_y = \frac{\partial\omega}{\partial k_y}, \quad v_z = \frac{\partial\omega}{\partial k_z} \tag{18}$$

The group velocity is physically observable, because the probability maxima and the speed with which they move are physically observable. The group velocity is equal to the classical velocity of a particle in a force field, because

$$E = \hbar\omega = \frac{p^2}{2m} + V(r)$$

$$\hbar\omega = \frac{\hbar^2 k^2}{2m} + V(r)$$

$$\omega = \frac{\hbar k^2}{2m} + \frac{V(r)}{\hbar}$$

$$v = \frac{\partial\omega}{\partial k} = \frac{\hbar k}{m} = \frac{p}{m}$$

$$= \sqrt{\frac{2}{m}[E - V(r)]} \tag{19}$$

which is the classical particle velocity.

A case which illustrates a quantum-mechanical description of physical states is that of a particle having an approximate energy $\hbar\omega_0$ and an approximate momentum $\hbar\mathbf{k}_0$ in an initial position near $\mathbf{r}_0$. (We cannot specify these quantities exactly because of the uncertainty relations.) To localize the particle, we put $\psi(\mathbf{r}, t = 0) = f(\mathbf{r} - \mathbf{r}_0)e^{i(\mathbf{k}_0 \cdot \mathbf{r})}$ where $f(\mathbf{r} - \mathbf{r}_0)$ is a function having an appreciable value only near $\mathbf{r} = \mathbf{r}_0$. This ψ is said to represent a "wave packet" (Fig. 3).

Average values (those actually observed in experiments) are obtained by integrating the variable in question over all space, after multiplying by the probability density to weight the quantity properly, much as centers of gravity are obtained in mechanics. Just as in mechanics $x_{av} = \frac{\int \rho x dv}{\int \rho dv}$ we use as the quantum mechanical average of x

$$x_{av} = \frac{\int \psi^* x \psi dv}{\int \psi^* \psi dv}$$

$$= \int \psi^* x \psi dv \text{ by normalization.} \tag{20}$$

The x is placed in between the wave function and its conjugate because we sometimes wish to evaluate "operators" like $\frac{\hbar}{i}\frac{\partial}{\partial x} = p_x$. It can be shown that, in these cases, the operator must be applied in between the wave function and its conjugate to give the correct average value.

Thus, the "center" of the wave packet, or average value of the position of the particle represented by it, is

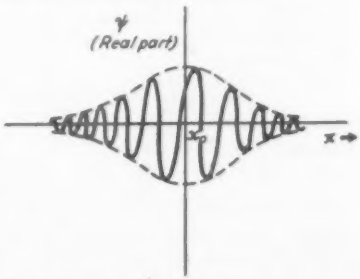


FIG. 3. Wave packet at $t = 0$.

$$\psi_{av} = \int f(\mathbf{r} - \mathbf{r}_0)e^{-i(\mathbf{k}_0\cdot\mathbf{r})}\psi f(\mathbf{r} - \mathbf{r}_0)e^{i(\mathbf{k}_0\cdot\mathbf{r})}d\tau$$

where $d\tau = dxdydz$

It can be shown that the center of gravity of such a wave packet moves in a potential field just as a classical particle does, but the packet spreads out as time goes by. We would expect this spreading out from a consideration of the uncertainty principle, which provides an uncertainty in momentum leading to an increased uncertainty in position.

An extremely important starting point in nuclear scattering problems is a beam of particles having a well-known energy and momentum. We represent this beam by $\psi = Ae^{i(\mathbf{k}_0\cdot\mathbf{r} - \omega t)}$, a plane wave. If the transverse dimensions are large compared with the wavelength of the particles, the transverse position is indeterminate and the corresponding momentum is therefore closely known. This indeterminacy in position is analogous to the classical theory of scattering where the impact parameter is not known for individual particles. According to the wave function ψ above, the energy of the impinging particles is $\hbar\omega_0$, their momentum $\hbar\mathbf{k}_0$. This formulation neglects any interaction between the particles themselves, which will be the case for sufficiently low particle densities.

A problem now arises as to the normalization of the wave function. This can be treated by setting the wave function $\psi = 0$ outside of a cylinder of convenient radius, giving

$$\int \psi^*\psi dv = A^2 \int dv = A^2V = 1;$$

$$A = \frac{1}{\sqrt{V}} \quad (21)$$

where V is the volume of the cylinder. Then Pdv represents the ratio of the number of particles in dv to the total number in V. Another method of treatment is to let ψ represent the wave function throughout all spaee, and interpret $Pdv = \psi^*\psi dv$ as the *number* of particles in the region dv, so P is the density of particles. Then $\mathbf{i}$ is the intensity of the beam of particles with a magnitude equal to the number of particles passing per unit area per unit time normal to the direction of the beam, which is also in the direction of $\mathbf{i}$. If $|\mathbf{i}| = n$, the number of particles passing per unit area per unit time will equal the density of the particles times their speed $|\mathbf{v}|$ to satisfy the equation of continuity.

Thus we have $\mathbf{i} = P\mathbf{v}$ and since

$$P = \psi^*\psi = Ae^{-i(\mathbf{k}_0\cdot\mathbf{r} - t)}Ae^{i(\mathbf{k}_0\cdot\mathbf{r} - t)} = A^2$$

then $n = A^2v$, and $A = \sqrt{\frac{n}{v}}$

For non-relativistic velocities $|v| = \frac{|p|}{m}$ $\frac{\hbar|k_0|}{m}$,

so $$A = \sqrt{\frac{nm}{\hbar k_0}} \quad (22)$$

Stationary States

Of particular interest are those quantum-mechanical states which remain unchanged for a long time (theoretically, indefinitely). These are known as stationary states. As measurement of their energy can be made over a long period of time, their energies are very closely fixed $\left(\Delta E \sim \frac{\hbar}{\Delta t}\right)$. The observed quantities connected with these states can be calculated from their quantum-mechanical averages, but for this we must first know the value of the wave function ψ.

For a stationary state, P and $\mathbf{i}$ should be time-independent. Since $P = \psi^*\psi$, we will have a stationary state if $\psi(\mathbf{r}, t) = u(\mathbf{r})e^{if(t)}$ Note that ψ is not time-independent in a stationary state. It need not be stationary because it is not physically observable. However, $\psi^*\psi = u^*(\mathbf{r})u(\mathbf{r})$ is time-independent. The form of $f(t)$ is determined by the fact that the total energy is given by $-\frac{\hbar}{i}\frac{\partial\psi}{\partial t} = H\psi$, where $H = E =$ total energy.

Thus $-\frac{\hbar}{i}\frac{\partial\psi}{\partial t} = -\frac{\hbar}{i}u(\mathbf{r})\mathbf{i}\frac{df}{dt}e^{if/t} = -\hbar\frac{df}{dt}\psi$. This means $E = -\hbar\frac{df}{dt}$ so

$= -\frac{Et}{\hbar} + \text{const.}$ Absorbing $e^{i\,\text{const}}$ into $u(\mathbf{r})$ gives

$$\psi = u(\mathbf{r})e^{-i\frac{Et}{\hbar}} \qquad (23)$$

for stationary states. Since $E = \hbar\omega$, $\psi = u(\mathbf{r})e^{-i\omega t}$, substituting in the Schroedinger time-dependent equation (12) gives, since $\frac{\partial\psi}{\partial t} = -i\omega u(\mathbf{r})e^{-i\omega t}$ and $\frac{\partial^2\psi}{\partial x^2} = \frac{\partial^2 u(\mathbf{r})}{\partial x^2}\, e^{-i\omega t} \frac{\hbar}{i}\,(-i)\omega u(\mathbf{r})e^{-i\omega t} +$ $\left[\frac{\hbar^2}{2m}\nabla^2 - V\right] u = 0$ or

$$\nabla^2 u + \frac{2m}{\hbar^2}(E - V)u = 0 \qquad (24)$$

This equation is known as the time-independent Schroedinger equation. Its solutions, multiplied by the exponentials $e^{-i\frac{Et}{\hbar}}$, represent the stationary states of a system. When $V(\mathbf{r})$ is specified, it is possible, given the boundary conditions, to solve the equation. It has been found that it is only possible to solve the equation for certain values E, which are known as eigenvalues of the energy; the corresponding functions $u(\mathbf{r})$ are known as eigenfunctions. In general, there are an infinite number of eigenvalues of the energy, but they are not necessarily continuous. This means that the system may make jumps from one of these discrete states to another, generally of different energy, and give off or absorb definite amounts of energy in the process, a fact recognized from atomic spectra long before the present form of quantum mechanics was evolved. The eigenfunctions $u(\mathbf{r})$ are important not only because of their use in solving stationary state problems, but because we can, by expanding a function representing a non-stationary state in terms of the eigenfunctions, deduce its subsequent behavior. Problems which differ only slightly from a previously solved one (perturbation problems) are solved by using the eigenfunctions of the solved problem.

It may be instructive to solve this equation for a particular case. A simple one is that of a free particle in a rectangular box of dimensions a, b, and c. For a free particle $V = 0$, so $\nabla^2 u + \frac{2m}{\hbar^2} Wu = 0 = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}$ $+ \frac{2m}{\hbar^2} Wu$. Trying a solution of the form $u = X(x)Y(y)Z(z)$, we get $\frac{d^2X}{dx^2} +$ $k_x^2 x = 0$ and similarly for y and z. Thus $u = A \sin k_x x \sin k_y y \sin k_z z$. We note that perfectly reflecting walls require that u be zero at $x = 0, a$; $y = 0, b$; $z = 0, c$; and also outside the box. Since $\sin \alpha a = 0$, etc., then $\alpha a = \pi n_x$ (n_x integer)

and $\qquad k_x = n_x \frac{\pi}{a},\ k_y = n_y \frac{\pi}{b},\ k_z = n_z \frac{\pi}{c}$

Also $\quad k^2 = k_x^2 + k_y^2 + k_z^2 = 2m\frac{W}{\hbar^2}$.

Then substituting in Schroedinger's equation (24) gives $W = \frac{\hbar^2\pi^2}{2m}\left(\frac{n_x^2}{a^2} + \frac{n_y^2}{b^2} + \frac{n_z^2}{c^2}\right)$.

To normalize the eigenfunctions, we require that $\int_{\text{all space}} u^* u\,dv = 1$

$$\int_0^c \int_0^b \int_0^a A^2 \sin^2\frac{n_x\pi x}{a} \sin^2\frac{n_y\pi y}{b} \sin^2\frac{n_z\pi z}{c}\, dx\,dy\,dz = A^2\left(\frac{a}{2}\right)\left(\frac{b}{2}\right)\left(\frac{c}{2}\right) = 1$$

Hence $A = \sqrt{\frac{8}{V}}$ (V = volume of box)

and $u = \sqrt{\frac{8}{V}} \sin\frac{n_x\pi x}{a} \sin\frac{n_y\pi y}{b} \sin$ $\frac{n_z\pi z}{c}$, where n_x, n_y, n_z are any integers.

These discussions are intended only as an introduction to the elementary

principles of the subject. For complete treatments, refer to these textbooks:

The two most complete treatments are written in German and are:

KRAMERS, H. A.: "Theorie des aufbaues der materie," 2 vols. (1933).
"Handbuch der physik vol. 24/1." (1933).

No correspondingly complete treatment has been published in English in any single textbook, but the following are some of the best:

DIRAC, P. A. M.: "The Principles of Quantum Mechanics," 2d ed., Clarendon Press, Oxford, 1935.

CONDON, E. U., and SHORTLEY, G. H.: "The Theory of Atomic Spectra," Cambridge University Press, 1935.

KEMBLE, E. C.: "The Fundamental Principles of Quantum Mechanics, with Elementary Applications," McGraw-Hill Book Company, Inc., New York, 1937.

FRENKEL, J.: "Wave Mechanics, Advanced General Theory," Clarendon Press, Oxford, 2 vol., 1934, 1936.

Many readers will want to begin studying from presentations which are more elementary. Examples are:

DUSHMAN, S.: "The Elements of Quantum Mechanics," John Wiley & Son, Inc., New York, 1938.

ROJANSKI, V. B.: "Introductory Quantum Mechanics," Prentice-Hall, Inc., New York, 1938.

It would be advisable to supplement readings in these articles with more detailed treatments. For instance, the reader should consult one or more of these references in investigating the solution of the Schroedinger equation for a particle in a Coulomb field, and the quantum-mechanical treatment of the harmonic oscillator problem, both omitted here for lack of space.

BERYLLIUM

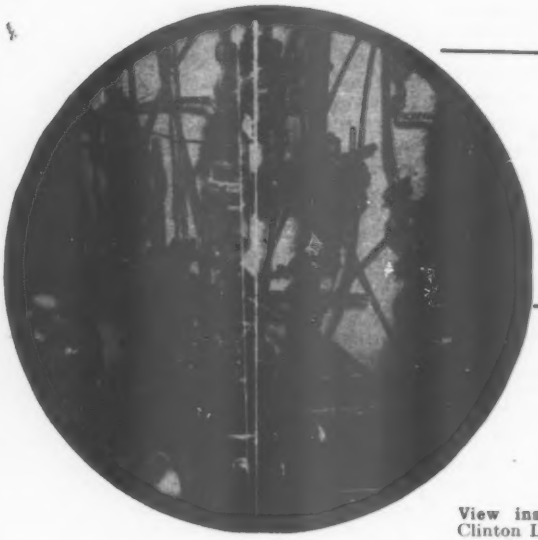
SOURCE OF NEUTRONS. "The neutron has been called the theme song of nuclear energy, it being the most effective particle for inducing nuclear changes, such as fission of U^{235}. The most common source of neutrons is a mixture of radium and beryllium where the alpha particles from radium and its decay products penetrate the Be^{9} nuclei, which then give off neutrons and become stable C^{12} nuclei (ordinary carbon).

MODERATOR. "The function of a pile moderator is to slow down or moderate fast neutrons to that velocity at which maximum fission capture is possible. The characteristics of a good moderator are that it should be of low atomic weight and that it should have little or no tendency to absorb neutrons. Beryllium, fourth in the periodic table, and the stable metal of lowest atomic weight, meets these requirements. Other possible moderators are hydrogen, deuterium, heavy water, and carbon. In addition to the above characteristics, the operation of piles at high temperatures for the production of power require that the moderator also have a high melting point, be stable at elevated temperatures, possess good hardness and strength, etc. Both beryllium metal and beryllium oxide possess these qualities to a high degree" . . . (*From a display in a "nuclear fission demonstration exhibit" by the Brush Beryllium Co., Cleveland, Ohio*).

"*It is not enough* to tell someone a secret; it is very hard to give away a secret. You have to work at it week after week because these things are complex. Only the creation of a really widespread and informed understanding of the techniques of atomic energy will get work on these problems advanced rapidly and with full effectiveness."

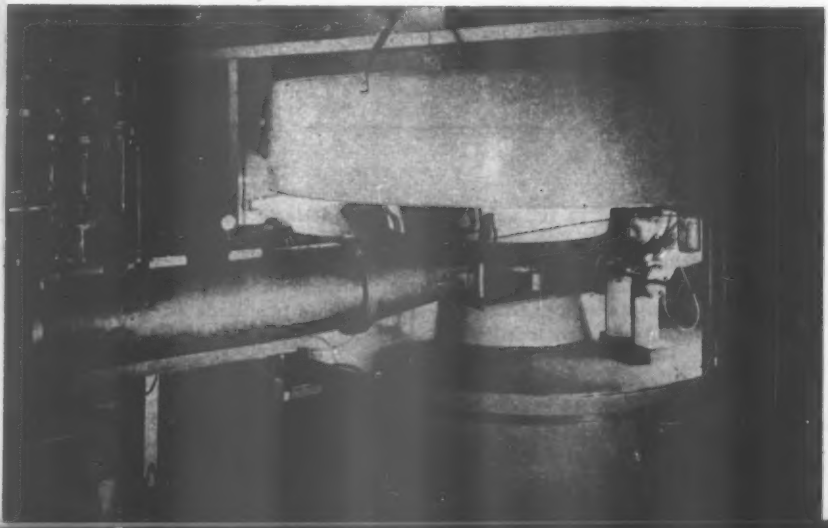
. . . *J. Robert Oppenheimer*, Bulletin of the Atomic Scientists, *July*, 1947

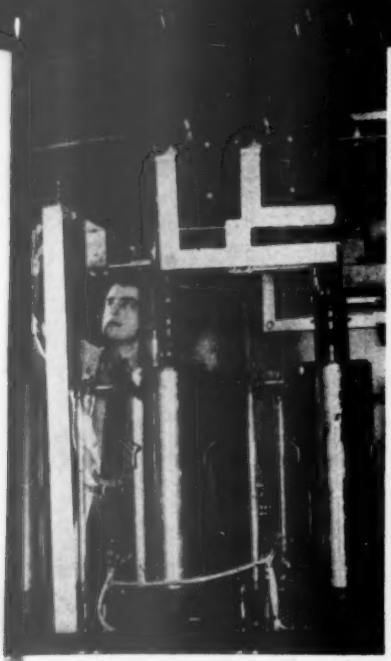
LAB SHOTS



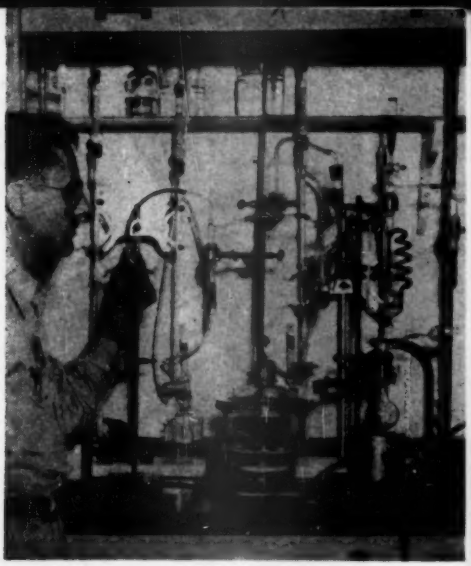
View inside a "hot" cell, at the Clinton Labs (Oak Ridge, Tenn.), as seen through a periscope, shows equipment necessary for chemically processing highly radioactive materials.

Assembling final stages of world's third largest cyclotron, recently placed in operation at the University of Pittsburgh, laboratory technician adjusts copper "dees" between poles of 100-ton electromagnet. During operation, the dees are enclosed in a duralumin vacuum chamber where ions are accelerated to a speed of 20,000 miles per sec.

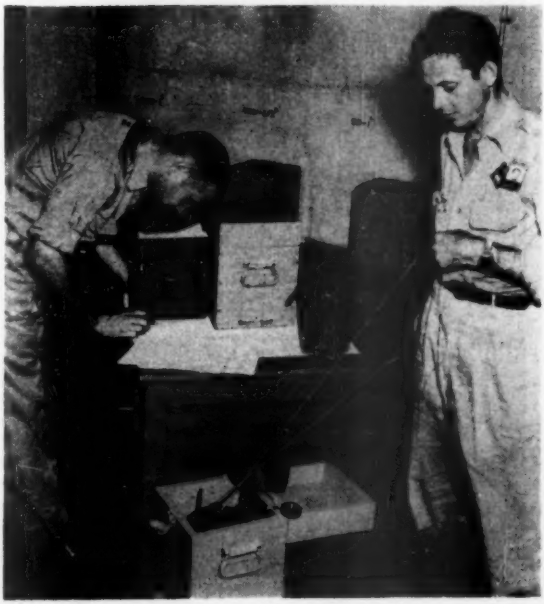




Ignitrons used to regulate two synchrotrons, rated at 300 Mev, being built by the University of California and M.I.T. Shown being assembled into control units by the Power Electronics Division of G. E., the tubes will control the magnitude and timing of current pulses in the synchrotron magnets.



Equipment for making radioactive carbon compounds is adjusted at Clinton Laboratories. The operator uses rubber gloves to protect himself from radioactive material.



A shipment of radioactive iodine in a small glass bottle is placed inside a lead shield by a technician at Clinton Labs. Bottle is handled on the end of a long string to eliminate exposure to excessive radiation. Other technician checks the radiation on another radioisotope shipment to make certain that safe limits are not exceeded.

FIRST GRADUATES OF THE CLINCH COLLEGE FOR NUCLEAR KNOWLEDGE

First Row, l. to r.: J. R. Menke (Kellex Corp.), L. A. Matheson (Dow Chemical Co.), K. O. Donelian (Kellex Corp.), S. Siegel (Westinghouse), F. Seitz (Carnegie Tech.), E. C. Campbell (Princeton Univ.), A. V. Masket (Naval Research Lab.), N. M. Smith, Jr. (Kellex Corp.). *Second row:* J. J. Markham (formerly Brown Univ.), G. A. Morton (R.C.A. Labs.), D. E. Hull (Carbide & Carbon), J. W. Kent (California Res. Corp.), L. D. Roberts (General Electric), D. J. Crowley (Socony-Vacuum Labs.), W. L. Davidson (B. F. Goodrich Co.). *Third Row:* F. C. Vonder Lage (formerly U. S. Navy), A. P. Webes (Kellex Corp.), H. C. Ott (Rensselaer Poly. Inst.), H. G. MacPherson (National Carbon Co.), W. I. Thompson (Standard Oil Dev. Co.), J. E. Hill (Westinghouse), R. C. Mason (Westinghouse). *Back row:* P. J. Bendt (General Motors), L. I. Eisenbud (formerly McLaughlin Carr Associates), H. M. Clark (Rensselaer Poly. Inst.), S. Lawroski (Esso Laboratories), J. J. Grebe (Dow Chemical Co.), J. I. Hoover, E. P. Blizard (Navy Dept.). *Trainees not appearing in picture:* E. B. Ashcraft (Westinghouse), R. M. Boarts (Univ. of Tenn.), J. H. Buck (Socony-Vacuum Labs.), L. P. Hunter (Westinghouse), S. M. MacNeille (Eastman Kodak), R. F. Newton (Purdue Univ.), W. H. Yanko (Monsanto).

Training in Nuclear Technology

By CLARK GOODMAN
Associate Professor of Physics
Massachusetts Institute of Technology
Cambridge, Massachusetts

ON THE EVENING of June 26, 1947, in Jefferson Hall, Oak Ridge, Tenn., the first class was graduated from the Clinch College for Nuclear Knowledge.*

While not as spectacular as the ceremonies held at some of the eastern universities, the Clinch Commencement was unusual in one respect—each of the 35 graduates received a doctor's degree. Since most members of the class already possessed the conventional Ph. D. or D. Sc., a new degree was awarded—*Doctor of Pile Engineering*. Prof. Frederick Seitz, first prexy of Clinch College, bestowed upon each candidate all the rights and privileges of placing the letters DOPE after his name.

Dr. Eugene P. Wigner presented the commencement address, "A Day at Clinch College." His speech was exceptional in two respects: It was interesting, and it was only four minutes in duration. Dr. Wigner, ending optimistically, noted that, as a result of the knowledge diffused at Clinch College, he expected to "see piles springing up all over the country."

Present and Future Developments

These facetious festivities marked the successful completion of the first stage of an important educational experiment in nucleonics. With the shift in emphasis from military to peacetime applications of nuclear energy, the urgent need for engineers trained in the rapidly expanding field has made itself evident. However, most of the technological developments remain classified. Hence, the colleges and universities throughout the nation, while well aware of the demand for this type of training, have been reluctant to initiate curricula in nuclear engineering. It is anticipated that the Atomic Energy Commission will soon establish a clearly defined policy placing the responsibility for much of this training in the hands of these educational institutions.

In the interim while a few universities and colleges are conducting courses in nuclear engineering within the bounds of unclassified information, the major educational efforts have been made in the training schools at the Clinton Laboratories and Fairchild Engine and Airplane Corporation in Oak Ridge and at the General Electric Company in Schenectady. The Argonne and Brookhaven National Laboratories have ambitious educational plans.

In the first Scientific Progress Report from Brookhaven, Dr. Philip M. Morse, director, made the following statement: "Brookhaven National Laboratory will provide extraordinary facilities for basic research in the physical, chemical, biological, medical, and engineering aspects of atomic science and for the training of scientific workers in these fields—facilities that cannot be provided with reasonable economy at universities and other research institutions. These facilities will be planned to meet the needs and interests of the many potential contributors to atomic science in the northeastern area, where up to now such machines as chain-reacting piles have been notably lacking. The need for men with this training is urgent at all research institutions. The present demand from industry for such scientists and engineers is expected to increase greatly as the new knowledge and techniques are applied to meet human needs. Accommodations adequate for training several hundred young scientists, in-

* Generally accepted pseudonym for the Training School at Clinton Laboratories.

cluding graduate students, are contemplated in the Brookhaven program."

Clinton Laboratories Curriculum

During the past year the training school at Clinton Laboratories has conducted the following courses:

Project Survey—F. Seitz

A semi-popular survey of items of general interest concerning the work at Clinton Laboratories and related work at other project sites.

Pile Neutron Physics—H. Soodak and A. M. Weinberg

A survey of the theory of neutron diffusion, reproduction constants, critical size, lattice structure, pile kinetics and the elements of pile design employing the more important mathematical techniques.

Pile Technology—G. Young

A survey of the more important technical features of piles including moderators, reflectors, coolants, heat transfer, shielding, materials of construction, source materials and economics.

Radiation Chemistry and Physics—A. O. Allen and F. Seitz

The effects of irradiation on the chemical and physical properties of gases, liquids and solids.

Theoretical Nuclear Physics—C. L. Critchfield, E. Greuling, L. W. Nordheim, R. D. Present, D. G. Rose, K. Way and E. P. Wigner

A general review of the theories of nuclear structure and nuclear processes using quantum mechanical methods.

Experimental Nuclear Physics—S. De Benedetti, H. W. Newson, A. H. Snell and E. O. Wollan

A general survey of instrumentation and its application to basic experiments in nuclear physics.

Radiochemistry—G. E. Boyd and H. A. Levy

Lectures and laboratory work on the chemistry of the fission products and the techniques of radiochemical analysis.

Chemistry of the Heavy Elements—K. A. Kraus and R. W. Stoughton

A survey of the important chemical characteristics of the elements near the end of the periodic system.

Principles and Practices of Separation Processes—W. E. Cohn and R. W. Stoughton

Consideration of problems involved in the separation of highly radioactive tracer materials from a bulk matrix, with particular emphasis on existing and proposed plutonium and fission-product separation processes.

Quantum Mechanics—E. Greuling

A general review with applications to nuclear structure and nuclear processes.

Fairchild Program

The Fairchild Engine and Airplane Corporation is the prime contractor under the Army Air Forces for the development program of Nuclear Energy for Propulsion of Aircraft (NEPA). As part of the combined operations of ten aircraft engine companies and the National Advisory Committee for Aeronautics, a training school has been in progress for several months. Organized by S. H. Turkel, Director of Technical Information, and Don Cowen, head of the Education Department, the program follows a ten-day seminar held last February. About 75 physicists, chemists, metallurgists, and engineers selected from the associated companies are taking the following courses:

Nuclear Science and Engineering—M. Deutsch, B. Feld, C. Goodman, J. W. Irvine, Jr., L. A. Ohlinger and H. Soodak

Fundamentals of nuclear physics with detailed survey of the fission process; neutron diffusion and elementary pile theory, design and construction of nuclear reactors; kinetics, control and operation of nuclear reactors; basic chemistry of the heavy elements and of the fission process; engineering aspects of nuclear reactors.

Experimental Nuclear Physics—S. De Benedetti and A. C. G. Mitchell

Aircraft Engineering and Pile Application—A. Kalitinsky and D. Poole

Descriptive survey of: practical aerodynamics (subsonic, supersonic); aircraft design criteria—lift, drag, stability, power, landing speed; aircraft performance—endurance, range, payload, speed, climbing, ceiling; performance limitations—power requirements, transsonic stability, dynamic heating; missile ballistics—mass ratio, specific impulse, aerodynamic limitations, guidance; practical thermodynamics—entropy charts, power cycles, cycle limitations; heat transmission—conduction, convection, radiation; power plant types (turbines, turbo-jets, ram jets, rockets)—performance criteria, efficiency, fuel consump-

tion, specific impulse, weight, cooling, drag, cost and maintenance; design criteria and limitations—pressure, temperature, dimensions; metallurgy and technology of materials—creep strength, ductility, machinability, corrosion, stress analysis, thermal stresses; application of nuclear energy; reactor design criteria.

Metallurgy—M. Kolodney

Review of: production methods, the metallic state, solid solutions, intermediate phases, deformation of metals, annealing, grain structure, constitution diagrams, age hardening, physical properties, engineering alloys, fabrication of fissionable materials, powder metallurgy.

Mathematics—F. A. Ficken

Survey of: ordinary and partial differential equations, gamma functions, Bessel functions, Legendre functions, vector analysis, probability.

Nuclear Chemistry—W. J. Blaedel

Types of radioactivity, stability rules, nuclear reactions, fission and fission products, chemical effects of radiation, identification of radioactive species, carrier techniques, separation processes, systematic quantitative analysis in radiochemistry, applications of nuclear chemistry, chemical aspects of propulsion by nuclear energy.

General Electric Program

Having undertaken the operation of the Hanford Engineer Works and entered upon an experimental and developmental program in the field of nucleonics, the General Electric Company set up a training program for engineers to fit them for this new field.

This educational project was conducted on two levels—an advanced level for engineers who would require a thorough basic knowledge of the principles, mathematics, techniques and experience to prepare them for general over-all responsibility in the field, and an elementary level both for those working in contributing fields, such as instrumentation, control mechanisms, fuel structures, health controls, etc., and for personnel at the policy-making level who would have neither the time nor the need for the advanced-course level. The entire course was patterned after those conducted for many years by G. E. in other lines of engineering, a project which has been known as "the advanced engineering program."

The course, known as "the *advanced* course in nuclear engineering," consisted of 34 weekly lecture sessions of 4 hours each and extended from October, 1946, to June, 1947. Each week there was a problem assignment which was intended to require from 15 to 20 hours for its solution. Altogether, 29 problems were assigned. A lecture session usually embodied one two-hour lecture and two one-hour lectures.

With only minor exceptions the students were furnished with lecture outlines before each lecture in a form suitable for filling in during the course of the lecture. These outlines named reference material for collateral reading and study. They were not only helpful to the students but also required the lecturer, who had had no previous pedagogical experience, to organize his material.

A four-day inspection trip to the Hanford Engineer Works included, as part of the course, 14 hours of lectures by personnel there.

The curriculum was set up with the assistance of the Knolls Atomic Power Laboratory personnel at G. E. and after consultation with the Clinton Laboratory people who were already doing educational work. The difference in need resulted in a difference in approach. The advanced course was devised as a single integrated course to cover all aspects of nuclear engineering with the relative emphasis according to the requirements. In broad outline the curriculum has been as follows:

SUBJECT	*LECTURE HOURS*
Introduction Survey of Nuclear Energy	3
Quantum Physics	5
Apparatus of Nuclear Physics	7½
Nuclear Physics	17½
Health Hazards and Protection	3
Pile Technology	14
Pile Operation	7
Pile Neutron Physics	42½
Mathematics of Transform Pairs	1
Chemistry	5
Pile Design	9
Metallurgy	4
Material Control	1½
Hanford Engineer Works lectures	14
Quizzes	3
Class discussions	4½
General	8½

In general, each subject was subdivided and handled by more than one lecturer. For instance, for *Pile Technology* there were four lecturers and for *Pile Neutron Physics* there were seven. This required the course supervisors to organize the subject matter more carefully but offered the advantages that each lecturer could stay closer to his special field. The lecture load was thereby spread more evenly over personnel whose primary function was carrying on the developmental and experimental work of the Knolls Laboratory. The course necessarily dealt with much classified material and the proper methods were worked out to handle this phase of the project.

The student body was recruited from company engineers who showed an interest in the new field or were already working in it and had the necessary background and analytical ability, as shown by their previous records in the advanced course program or by the quality of their work. Of the twelve students who started this course, ten finished. It is hoped to make such a course a regular part of the annual advanced engineering program.

The lower-level course, known as "the *project* course in nuclear engineering," extended over 24 weekly sessions of two hours each. Outlines were furnished the students. The curriculum was a scaled-down version of the advanced course both in time and content. There were no required assignments and far less classified material. The student body reached a maximum of 73.

M. I. T. Curriculum

Following a three-day classified conference attended by about 40 members of the staff in July, 1947, it was decided that no classified subjects in nuclear science and engineering would be included in the curriculum at the Massachusetts Institute of Technology. Consideration was given to the desirability of establishing a new course in nuclear engineering for undergraduates and graduates. At the present time this is considered premature. Instead interested students in all departments are encouraged to select their programs from the following nuclear subjects available in the departments of physics and chemistry:

Introduction to Nuclear Physics (for undergraduates)—M. Deutsch

Survey of the principal fields in nuclear physics; static properties of atomic nuclei, binding energy, nuclear models; radioactive transformations; properties of charged particles, neutrons and gamma rays; transmutation, fission, artificial radioactivity.

Nuclear Physics I—R. D. Evans

Advanced experimental nuclear physics, including description of the properties of nuclei and nuclear transformations, observational methods and instruments and correlation of experimental results with current theory; charge, mass, radius, nuclear moments, statistics, parity, and selection rules for nuclear transitions; interaction between particles, binding energy, nuclear models; radioactive transformations, theory of statistics and fluctuations.

Nuclear Physics II—R. D. Evans

Ionization, scattering and radiative losses for swift charged particles; properties of neutrons; origin of gamma rays and their interaction with matter; transmutation, fission, reactions induced by charged particles, gamma rays, and neutrons; excitation functions; artificial radio activity, nuclear spectroscopy.

Nuclear Physics Laboratory—M. Deutsch

Study of the properties of particles from natural, artificial and fission disintegrations and the corresponding measuring instruments; use of counters, coincidence amplifiers, ionization chambers, and the cyclotron.

Cosmic Rays and High Energy Phenomena—B. B. Rossi

Mesons and their occurrence in cosmic rays and interaction with nuclei and heavy particles, showers, cascades; artificial production of mesons and their properties.

Theory of Nuclear Structure—V. F. Weisskopf

Review of the current theories of the structure of atomic nuclei; nature of internuclear forces; calculation of nuclear binding energies, collision, excitation functions for transmutation, fission including reactions induced by neutrons, light or heavy charged particles, gamma rays; theory of alpha and beta radioactivity.

Nuclear Science and Engineering—C. Goodman

Static and dynamic properties of nuclei of importance in the release of nuclear energy.

elementary theory of neutron diffusion, application of elementary pile theory to the design and control of nuclear reactors, survey of suitable materials of construction, shielding, and health hazards.

Special Problems in Nuclear Physics—R. D. Evans

Experimental work on radioactivity, nuclear bombardment, and general nuclear research, with assigned reading and consultation.

Radiochemistry—C. D. Coryell and J. W. Irvine, Jr.

Chemistry of the production, isolation, and identification of radioactive atoms; introduction to the techniques of preparation and measurement of radioelements; applications of these techniques to chemical problems; laboratory study of special topics including radiochemical analysis, the fission process, and the reactions following nucleogenesis.

Introduction to Radiation Chemistry—L. Harris

Structure of atoms as inferred from results of experiments; deflection of charged particles in electric and magnetic fields, interaction of matter with charged particles or neutral particles of high velocity; emission and absorption of radiation. Discussion of these results and the periodic table in terms of the quantum theory; transition to the study of molecular structure provided through the concepts presented.

Advanced Radiation Chemistry—L. Harris

Modern statistical methods for calculating macroscopic properties such as free energy, entropy, and heat capacity require a knowledge of the microscopic properties of molecules. These properties such as bond strengths, internuclear distances, atomic angular distribution, nuclear spin, and dissociation energies are derived from spectroscopic data. The mechanics of molecular motion are considered, and with the aid of the quantum theory, the relation of molecular constants to spectroscopic constants is derived. The primary reactions of photochemistry are interpreted in terms of the spectra.

Heretofore, nuclear physics has been an elective subject for undergraduate physics majors. Beginning this fall some nuclear physics will be included at the sophomore level, and the introductory subject given by Prof. Deutsch will be required in the second term of the junior year. This subject has the following two prerequisites, which will be taken the first term of the junior year:

Atomic Structure—H. Mueller

Electron and ion beams, and scattering of alpha-particles, electrons, and light by atoms; the corpuscular nature of light and the wave nature of the electron; the Bohr theory of atomic structure and the vector model of the atom; radioactivity and nuclear structure.

Atomic Structure Laboratory—W. W. Buechner

Application of laboratory techniques to the study of selected topics in modern physics such as absorption and emission spectra, inelastic impacts of the first and second kind, resonance radiation, fluorescence, critical potentials, gamma-ray absorption and artificial radioactivity.

Thus, the study of atomic nuclei is preceded by a comprehensive survey of the structure of atoms as a whole. During the senior year, the physics major may elect to take any of the more advanced subjects in nuclear physics, radiochemistry, or radiation chemistry.

Undergraduates in other departments, by suitable adjustment of their regular curricula, can also elect nuclear courses in the junior and senior years. Graduate students working toward the Master's degree in departments other than physics and chemistry can fulfill their minor requirements by taking three or more of the above subjects. For example, a Master's candidate in Chemical Engineering can obtain basic training in nuclear engineering by taking as minor subjects:

Atomic Structure
Introduction to Nuclear Physics
Nuclear Science and Engineering
Radiochemistry

The schedules are so arranged that these subjects can be taken in sequence over a two-year period. It is anticipated that a number of advanced-degree candidates will carry on their thesis research at engineering practice schools to be established at one or more of the national laboratories or at other sites of the Atomic Energy Commission. As in the past, a graduate receives his degree in the course in which his major work was done. However, the training received qualifies him to enter one of the several divisions of the broad field of nuclear engineering.

Electronic Instruments for Use with Geiger-Muller Tubes

Attainment of reproducible results in tracer research requires painstaking control over a complexity of variables. Analyzed here are some of the important instrumentation variables

By RAYMOND P. GHELARDI and CYRIL H. BROWN
Tracerlab, Inc., Boston, Mass.

AT THE PRESENT TIME, the Geiger-Müller counter tube is the basis of a large variety of measurements in nuclear research. Although this type of detector of ionizing particles was first constructed in its present form in 1928, it remains one of the most sensitive detectors yet devised. The motion of a single, high-speed electron from a radioactive source into the sensitive region of the tube can cause an electrical discharge which produces a voltage pulse across the electrodes of as much as 100 volts, depending on external circuit conditions. The literature on counter tubes is now almost endless. For a comprehensive review of the theory of operation of counters and for a bibliography of the literature, the reader is referred to Korff (*1*).

With the use of a Geiger-Müller tube, the problem of determining the average rate of arrival of randomly occurring ionizing radiations from a radioactive source becomes, in its simplest terms, a new problem of determining the rate of occurrence of the resultant electrical impulses across the terminals of the tube. (There are, of course, several efficiency corrections to be made to account for the fact that not every ionizing particle entering the counter tube produces a separate and identifiable voltage impulse.)

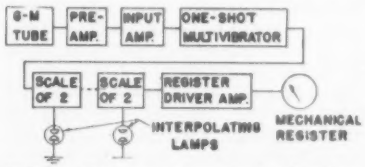


FIG. 1. Diagram of conventional scaler.

In determining the average rate of occurrence of the voltage impulses normally appearing (individually and collectively at random) across the terminals of the Geiger-Müller tube, there are two basic methods of data collection. The first involves counting the impulses during a preselected time interval. In this category fall the instruments that are simply electronic counters (now more frequently referred to as "scalers" to avoid confusion with counter tubes). Included, too, is the counting-rate meter, which indicates directly on a calibrated meter scale the average rate of arrival of the impulses. This instrument is considered in this category because its action is to average the number of impulses occurring during an equivalent time interval which is determined by the time-constant of the integrating circuit (*2*)(*3*). Several instrument manufacturers now market devices of this type.

The second of these two basic methods of data collection involves the measurement of the time necessary for the arrival of a predetermined number of impulses. The Autoscaler, described later, collects data by this method.

There are several factors that limit the utility and flexibility of one or more of these instruments. A statistical

error is associated with each measurement of the average counting rate of a finite number of impulses which are spaced at random intervals. The magnitude of the statistical error is proportional to the inverse square root of the total number of impulses counted. Thus, those measurement systems which lie in the first category have the general limitation that in the measurement of sources of different strengths different statistical errors are involved, since the number of events considered will vary if the observation time is kept constant. However, in the use of an instrument such as the Autoscaler, which falls in the second category, the statistical error remains fixed, since a preselected, fixed number of events is counted and the time it takes for their occurrence is measured.

Fig. 1 is a block diagram of the conventional electronic scaler. The Geiger-Müller tube output pulses are fed into the input amplifier, frequently through an appropriate preamplifier. This preamplifier may take on any one of several forms, depending on the type of Geiger-Müller tube used (whether selfquenching or non-selfquenching) and the desired input circuit arrangement. The signal from the input amplifier is made to trigger a "one-shot" or single-stroke multivibrator (a device that produces a single, rectangular-shaped pulse of constant width and amplitude suitable for triggering a scaling circuit) each time its input receives a triggering impulse (regardless of its shape or amplitude within certain limits). The output of this multivibrator is fed into the first of several scaling circuits. A scaling circuit acts as an impulse divider. One output pulse appears for each two input pulses that are received. Thus a series of n of these scaling circuits acts to multiply the input pulse rate by a factor of 2^{-n}. Usually just enough scaling circuits are used to reduce the input counting rate to a value which is slow enough to actuate consistently a mechanical counting register which would skip counts or else be totally inoperative at higher rates.

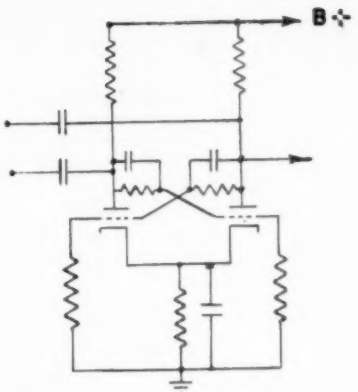


FIG. 2. Basic scale-of-two circuit.

Fig. 2 shows a typical circuit diagram of a basic scale-of-two circuit, showing the neon "interpolation" light which is used to determine if a count has been "left" in the electronic circuit at the end of the observation time.

The sequence of operation of the whole scaler is as follows: Either manually or automatically, a precision electric timer is started at the same time that pulses from the Geiger-Müller tube are first allowed to actuate the scaling circuit. At the end of the preselected time interval, the clock is stopped and the input pulses to the scaling circuit simultaneously removed so that they no longer actuate the scaling circuit. The reading of the mechanical register multiplied by the total scaling factor 2^n (where n is the number of scaling stages, usually not less than 3 nor more than 7) is added to the number of counts "left over" as indicated by the interpolation lights. The sum is equal to the number of counts received at the input in the time interval indicated by the precision electric timer. The total number of counts is then divided by the time interval to get the counting rate.

Of the instruments in common use at the present time, the only one that

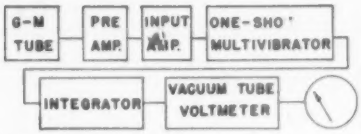


FIG. 3. Block diagram of a typical counting-rate meter.

presents the data in the form in which it is finally desired is the counting-rate meter. Fig. 3 is a block diagram of a typical counting-rate meter. As far as the one-shot multivibrator is concerned, circuit functions are similar to the corresponding sections of the typical scaler of Fig. 1. The output of the one-shot multivibrator is fed into an integrating circuit, such as is illustrated in Fig. 4. This integrator has a long time constant to smooth out of the meter reading those rapid fluctuations due to statistical variations in the counting rate. The vacuum-tube voltmeter connected across the integrating capacitor gives readings directly proportional to the rate of arrival of pulses at the input circuit. The effect of the time constant is to make the output reading of the instrument proportional to the integral of all pulses which have arrived, weighted exponentially according to the time elapsed since the arrival of the pulse (*2*) (*3*).

Although a cursory examination of the functions of all these instruments would seem to indicate that the counting-rate meter is most convenient to use because it gives its reading in the form usually desired for data, there are certain inherent limitations which restrict its usefulness. First, because of the fact that its measurements are based on an equivalent, fixed time-interval, the statistical error of measurement varies with the counting-rate indication. Second, because of the long time constant, the counting-rate meter is slow to change its meter reading when the input counting rate is changed from one value to another, as, for example, when a high-activity sample giving 15,000 counts per min is replaced with a low-activity sample giving only 2,000 or 3,000 counts per min. After changing the input counting rate appreciably, one must wait for a period of roughly two to five times the time constant to elapse (depending on the counting rate) to be sure that a reading will fall within the probable error at the new counting rate. Thus, for example, if the counting-rate meter is indicating the background count and a sample giving 8,500 counts per min is placed under the Geiger-Müller tube with a time constant of 40 sec, it would take more than three-min equilibrium time (by equation 9 of reference *3*) to insure that the reading was within one probable error (in this case $\pm 0.64\%$). A scaler, totalizing some 11,300 counts, would give the same answer to the same probable error in less than 1.4 min. If a probable error of $\pm 1.0\%$ were satisfactory, then a scaler totalizing about 4,500 counts would give the answer in a little more than one-half min.

In addition to the limitations outlined above, we have the fundamental difficulty that errors exist in the calibration of a counting-rate meter. Two per cent meter accuracy and slight changes in component values caused by temperature rise may combine to cause a possible instrument error of a few

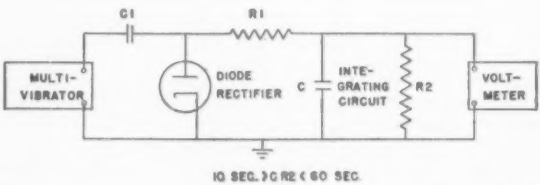


FIG. 4. Typical integrating circuit for counting-rate meter.

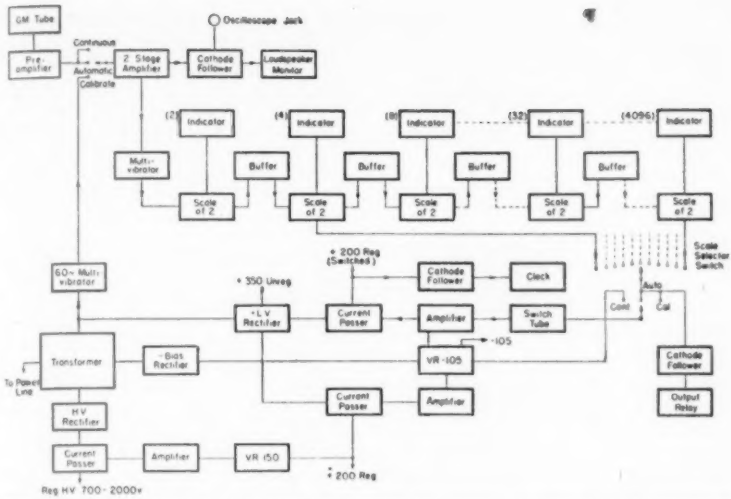


FIG. 5. Block diagram of Autoscaler, illustrating scaling sequence and automatic turn-off features.

per cent. Such calibration errors do not exist in a scaler, where vacuum tubes are used merely as on-off switches.

There are occasions, however, when the counting-rate meter is perhaps better suited to the purpose. If the counting rate of the series of samples to be measured can be kept approximately constant, then the equilibrium-time limitation of the counting-rate meter disappears. In addition, for those cases where a radioactive sample is to be continuously measured over a long time, as when determining radioactive decay rates, a good counting-rate meter would appear to lend itself admirably to the task, since an automatic moving tape recorder can be easily attached to it to give a permanent record of counting rate versus time. Here again, there is no equilibrium time involved. In addition, the statistical fluctuations apparent on the paper tape record can themselves be used as a basis for graphically computing the probable error of the measurements during the observation time. The counting-rate meter can also be easily adapted for use with automatic, machine-operated, sample-changer equipment, with at least the same facility as a scaler. Thus the choice between these two instruments becomes largely dependent on the use to which they are to be subjected.

The Autoscaler, shown in block diagram form in Fig. 5, is a complete unit for supplying the operating voltage for a Geiger-Müller tube, counting the impulses from this tube, and measuring the time required for the reception of a given number of these impulses.

Several of the more interesting circuits in the Autoscaler will be described in detail. Fig. 6 shows the circuit diagram of the preamplifier, which is separated from the main chassis by a convenient length of connecting pulse cable. This preamplifier is of a modified Neher-Pickering type (*4*). An inspection reveals that it is a form of cathode-follower circuit used in the communication and radar fields (*5*). A small part of its function is to provide a low impedance output, characteristic of a cathode follower, in order that the

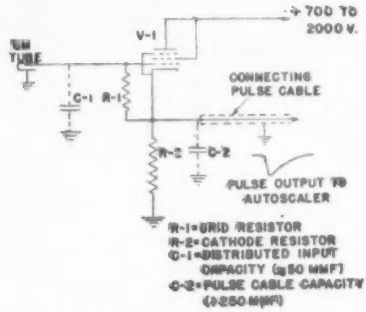


FIG. 6. Modified Neher-Pickering type preamplifier.

pulses from the Geiger-Müller tube may be sent down a length of connecting pulse cable without undue loss of pulse height or undue pulse stretching. This applies especially to the positive-going trailing edge because of the capacity loading of the cable (about 30 to 50 mmf per ft).

Since the control grid of the triode-connected tube V-1 (Type 6AK5) is returned to its cathode via R_1, the grid is at zero bias during the intervals between pulses. Under these conditions, the current through V-1 is determined by the value of the cathode resistor (R_2) selected and the magnitude of the high voltage applied. A value of 1×10^6 ohms will give "no signal" conduction currents between 0.7 and 2 ma for the applied voltage range shown. This insures the tube's operating in a plate current region where its transconductance (g_m) is high enough.

Since V-1 is at zero bias, there is only about a 25-volt drop between its plate and cathode. Almost the full applied voltage appears between the center wire system and grounded cylinder of the Geiger-Müller counter tube. This voltage can be varied anywhere between 700 and 2,000 volts. A value can thus be found that will operate practically all of the commercially available Geiger-Müller tubes in the center of their "plateau" region.

When an ionizing particle enters the Geiger-Müller counter tube, the avalanche of electrons momentarily lowers the potential of the center wire system, in some cases below the threshold voltage of the counter. The amount by which the voltage on the center wire drops with respect to ground is considerably in excess of the IR drop across R_1, since the negative charge on the control grid of V-1 tends to cut off its plate current, thereby lowering the positive potential of the cathode (junction of R_1 and R_2). The rate at which the cathode voltage drops is determined by the time constant of C_2 times the parallel combination of R_2 and the equivalent output impedance of the cathode-follower for the negative-going pulse. If the charge on the grid is enough to cut off the plate current momentarily, then this time constant becomes approximately R_2C_2. (The cathode will usually attain its maximum negative value within 1×10^{-6} sec for typical operating conditions.) As far as the Geiger tube is concerned, this has the same effect as keeping the cathode potential constant and instantaneously increasing manifold the resistance of R_1.

After this initial avalanche of electrons on the center wire, and during the time interval that the positive ion sheath is migrating toward the cylinder, the center wire potential rises exponentially towards its original value. The recovery time is largely determined by the speed with which the distributed capacity C_1 can recover its original voltage and is not affected appreciably by the capacity loading of the cathode by C_2. (For a positive-going pulse, the output impedance of the cathode-follower is extremely low and is thus able to recharge C_2 quickly. Experiments indicate that C_2 can be varied by factors of two without appreciably changing the recovery time of the circuit.

The recovery time of the circuit can be conveniently varied by proper selection of the value of R_1 since it has primary control over the speed with which C_1 can regain its original voltage. A value of 100,000 to 250,000 ohms will give a measured recovery time of the order of 50×10^{-6} sec for a typical value of C_1. This is desirable for use with selfquenching Geiger tubes, since

it is less than the "dead" time of these tubes (2 to 3×10^{-4} sec) (*6*). This allows such Geiger tubes to operate at their maximum-possible speeds and minimizes coincidence losses in counting.

For use with non-selfquenching counter tubes, R_1 can be changed to a value of 5 to 10×10^6 ohms, which will yield a recovery time of the order of 1×10^{-3} sec. This tends to keep the potential of the center wire low for a long-enough time to eliminate the false counts produced when the positive ion sheath is neutralized at the cylinder wall. In such a neutralization process, a few free secondary electrons are formed. With this arrangement the circuit is said to "quench" the discharge of the Geiger-Müller tube.

There are several other circuit arrangements (*7*) (*8*) that will achieve much the same results, and the choice is usually made on the basis of convenience. Some of these circuits, however, involve "floating" the cylinder of the counter tube above ground, which increases insulation problems and increases susceptibility to pickup of stray electrical disturbances. The insulation problem is especially evident when metal-cylinder, end-windowed counter tubes are used.

In addition to the above circuits, there is the well-known conventional or classical circuit which consists simply of a single series "quenching" resistor. For use with selfquenching counter tubes, the simplicity of this circuit is without equal. For use with non-selfquenching tubes, however, the value of this resistance must be made so large (approximately 10^9 ohms) that the recovery time of the circuit becomes excessively long. This is necessary because it is difficult to keep the distributed capacity below 25 mmf. If the resistance is made smaller, on the other hand, the length of the plateau of the counter tube is shortened. There appears to be no compromise value that will be satisfactory in all respects.

Fig. 6 shows that the negative pulses from the Neher-Pickering preamplifier are fed, via the cable, into a two-stage triode amplifier within the main chassis. Interstage RC peaking circuits are employed to produce sharp pulses of short duration suitable for reliably triggering a fast multivibrator.

These pulses are then applied to the one-stroke multivibrator (Fig. 7).

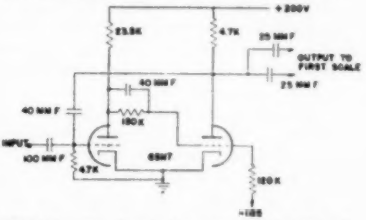


FIG. 7. Single-stroke or "one-shot" multivibrator. Output pulse width is approximately 2×10^{-6} sec.

Because of the high negative bias on the right-hand grid, the right-hand triode is normally completely cut off while the left-hand triode is normally conducting. When a negative pulse is applied to the left-hand grid, the left-hand tube is cut off and a positive pulse is fed through the RC coupling circuit to the right-hand triode, causing it to conduct. As the 40 mmf coupling condenser discharges through the 4.7K resistors, the left-hand tube is returned to the conducting condition and the cycle of operation is complete. Consideration of the voltage between the output lead and ground will show that a negative pulse is produced during the cycle. For the circuit values as given here, the duration of this output pulse at 90% of maximum amplitude is approximately 2×10^{-6} sec. The rise time may be of the order of 0.25×10^{-6} sec, depending on the distributed capacity of the plate and grid leads, etc. A quantitative treatment of the operation of multivibrators of various types can be found in "Principles of Radar" (*9*).

Fig. 8 shows one form of a fast scale-of-two circuit, employing a dual-triode tube such as the type 6SN7, 7F8 or 6SL7. Successive stages are separated by triode buffers biased considerably beyond plate current cut-off;

note that the two plate circuits are fed from different sources of B+ voltage. The right-hand plate is fed from an independently regulated supply. The left-hand plate is fed from a special regulated supply in which are included provisions for changing the B+ voltage from the 200 volts required for normal operation down to about 70 volts, when the scaling circuits are stopped and reset. This automatic switching system is described later.

The operation of the scale-of-two or "flip-flop" circuit has been well described elsewhere (*10*) (*11*), although Phelps appears to have been the first to clarify the vital role played by the small plate-to-grid coupling condensers. Briefly the operation is as follows: As the START button is depressed on the Autoscaler, the B+ switched supply voltage is raised from +70 v to +200 v. A consideration of the circuit will reveal that the left-hand triode will thus be made conducting (grid G_1 at 0 bias) and the right-hand triode (grid G_2) will be below cut-off as before. The values of the voltages on all grids and plates are then as indicated in the figure. The voltages in parentheses are obtained after the stage has "flipped."

The 25-mmf coupling condensers (C_1) are arranged to feed small, sharp, negative triggers of equal amplitude to both grids of the "flip-flop" when a large negative trigger appears at the plate of the preceding buffer stage. These negative triggers, appearing on both grids simultaneously, serve only to increase the negative voltage further on G_2. But the voltage on G_1 is reduced to cut-off.

The plate voltage on P_1 rises rapidly towards +180 v at a rate limited only by the distributed shunt capacity on P_1. Since the voltage across a capacitor cannot change instantly, the rapid rise of voltage on P_1 is transferred by C_2 almost without loss to grid G_2. The voltage on G_2 then rises rapidly toward the value at which plate current conduction starts in the right-hand triode. The *sine qua non* of operation appears to be that the "off" grid (G_2 in this case) must reach the voltage for plate current conduction *before* the negative charge from the trigger on G_1 has had a chance to leak off. If the charge leaked off, G_1 would of course rise toward zero bias, lowering the voltage on P_1 possibly back to 60 v. The vital role played by C_2 is now apparent.

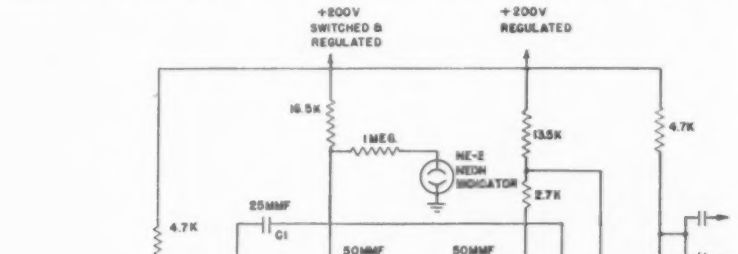


FIG. 8. Typical, fast, scale-of-two circuit. With proper physical layout, resolving time can be made less than 5×10^{-6} sec.

Without C_3, the "off" grid would not rise rapidly enough for the above condition to be satisfied, a fact easily verified by oscilloscope observation.

The value of C_2 should usually be at least $2C_1$ to insure that the potential difference across C_2 does not change appreciably for the duration of the negative pulse on the "on" grid. If C_2 is made too large, on the other hand, the production of large negative overshoots might limit the resolving time of the scale. The resolving time of the scale, as shown, has been measured to be about 5×10^{-6} sec for a typical wiring layout.

The 100-mmf condenser and the 47K grid resistor of the following buffer serve to take the sudden voltage changes on P_2 and form them into alternately positive and negative pulses of short duration. The buffer grid is biased to more than twice cut-off voltage, and allows only the positive pulses to be passed onto the next "flip-flop." Thus each scaling stags is made to pass one pulse for every two received. The sequence of waveforme of several stages is illustrated in Fig. 9.

Fig. 10 shows a circuit diagram of the automatic power supply switching circuit of the Autoscaler. In normal operating condition, with 200 volts output, the OA4G tube is not conducting, and the regulator is operating with normal bias on the 6SJ7. When the counting cycle is complete, the final pulse to be propagated through the scaler system is fed onto the starter anode of the OA4G. This causes the OA4G to conduct, increasing the voltage drop across the resistor R_1 and resulting in a dropping of the regular output voltage to approximately 70 volts. This drop in voltage halts the operation of the scaler circuits as previously outlined, and also reduces the value of plate current in the 6V6 tube to such a low value that the clock clutch is disengaged and the hands stopped. This series of stopping events, which may also be initiated by depressing the STOP button, is completed within 15 microseconds after the

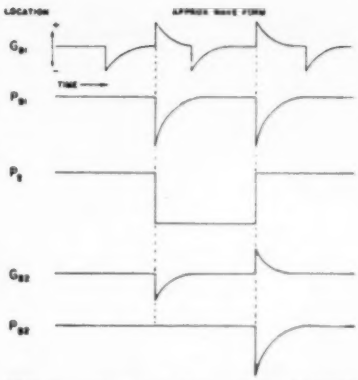


FIG. 9. Sequence of waveforms through scale-of-two circuit shown in Fig. 8.

initiating event. When the system is in the "off" condition, it is started by depressing the START button which opens the cathode circuit of the OA4G, returning it to the non-conducting condition, and raises the output voltage of the regulator to 200 volts so that the scalers may start operating. The plate current in the 6V6 is increased so that the clock once again begins to operate.

The matter of statistical error was mentioned earlier in the discussion of the advantages of the different types of counting instruments. If the radioactive emanations entering the Geiger-Müller tube occur individually and collectively at random, such that each ionizing event occurs independently and does not influence the next, then the process follows Poisson's Law (*12*) (*13*), given by

$$P_n = \frac{(n_{av})^n \times e^{-n_{av}}}{n!} \qquad (1)$$

where n_{av} is the average number of ionizing events occurring in a certain time, determined by very long observation; n is the actual number occurring in this time; and P_n is the probability that, in this time, n events will occur.

The expected deviation D or root-mean-square error of the number of events observed, from the true average, is defined as

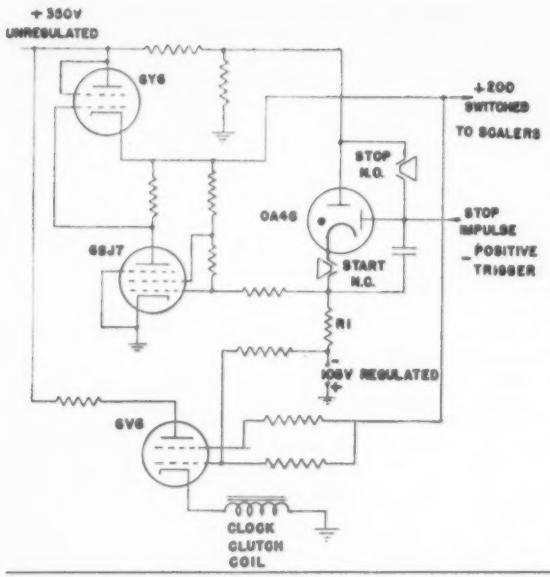


FIG. 10. Regulated low voltage power supply, with arrangement for lowering voltage output upon application of positive impulse to starter anode of the OA4G.

$$D = \left[\sum_{0}^{\infty}(n - n_{av})^2 P_n\right]^{1/2} \qquad (2)$$

Applying equation 1, the deviation then becomes

$$D = (n)^{1/2} \qquad (3)$$

provided n is large. The deviation is thus equal to the square root of the total number of events observed. The relative deviation is then

$$\frac{D}{n} = \frac{1}{(n)^{1/2}} \qquad (4)$$

Thus, for example, in measuring a radioactive sample in a single continuous observation, if 2,048 counts are totalized, the relative deviation is $D/n = 1/(2048)^{1/2}$ or $\pm 2.2\%$. If the time it took to totalize 2,048 counts was 25 sec, the counting rate would be expressed as 4,900 counts per min $\pm 2.2\%$.

The probable error $P.E.$ (defined as that error which is as likely to be exceeded as not) is, however, more frequently used than the deviation D. It is given by

$$P.E. = 0.6745D \qquad (5)$$

Hence, the relative or per-cent probable error (% $P.E.$) of any observation is

$$\%\ P.E. = \frac{67.45}{(n)^{1/2}} \qquad (6)$$

From equation 6, it will be seen that, to reduce the relative probable error to $\pm 1\%$, it is necessary to totalize only about 4,500 counts, but to reduce it to $\pm 0.5\%$, it would be necessary to totalize more than 18,000 counts! From a practical standpoint, it is not frequent that the excessive observation time necessary to reduce the relative probable error much below $\pm 1\%$ is outweighed by the advantage of the reduction in error. Thus, it is satisfactory in most measurements to totalize 4,000 or 5,000 counts. It is for this reason that the automatic scales in the Autoscaler have not been extended beyond 4,096 counts. This corresponds to a relative probable error of about $\pm 1.05\%$.

When a Geiger-Müller tube is used to measure low intensity radiation with a counting rate not many times the natural "background" counting rate of

the counter tube, it becomes necessary to know and take into account the effect of the background count on the statistical accuracy of the measurement. The radiation is first measured in the presence of the background count. The source is removed from the vicinity of the Geiger tube, then, and background count is determined. The net counting rate is then equal to the total counting rate minus the background counting rate. The relative probable error of the total counting rate remains as given in equation 6, but the relative probable error, expressed in per cent of the net counting rate, obviously increases by the ratio of the total counting rate to the net counting rate. There is an additional increase in error introduced by the fact that the background counting rate is not known precisely but has a probable error of its own. Statistically, the probable error of the difference between the total and background counting rate is equal to the sum of the squares of the individual errors of each.

The above relations may be expressed by a single equation

$$\% \ P.E. = \frac{67.45(N_t + N_b)^{1/2}}{N_t - N_b} \qquad (7)$$

where N_t is the number of counts totalized in arriving at the total counting rate, and N_b the number in arriving at the background counting rate.

R is defined as the ratio of the total counting rate to the background counting rate. In the case where $N_t = RN_b$, as when the total and background count are observed for the same fixed time interval, $1/R$ as many counts are totalized in arriving at the probable error of the background counting rate as in arriving at the probable error of the total counting rate. In this case, equation 7 reduces to the more familiar (*14*) form

$$\% \ P.E. = \frac{67.45\left(N_t + \frac{N_t}{R}\right)^{1/2}}{N_t} \times \frac{R}{R-1} \qquad (8)$$

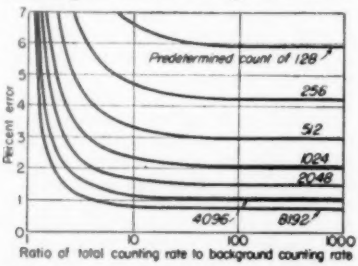


FIG. 11. Chart showing per cent probable error (% P.E.) in net counting rate for various predetermined counts, as a function of the ratio of total counting rate to background counting rate.

Equation 7 has been plotted in Fig. 11 where values of N_t available in the Autoscaler are plotted as a function of R and the per-cent probable error in net counting rate. The chart assumes that the same number of counts are totalized in arriving at the total counting rate as in determining the background counting rate, i.e., $N_t = N_b$.

Several facts immediately become apparent from the plot. First, if the total counting rate is kept at least ten times that of background alone, there is little increase in the error of the net counting rate. Second, there is only a little decrease in error when the number of counts totalized is increased from 4,096 to 8,192.

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PRODUCTS and MATERIALS

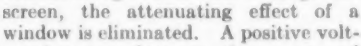
GEIGER-MÜLLER COUNTER

Berkeley Scientific Co., 601 Nevin Ave., Richmond, Cal. This counter has been built to give automatic voltage regulation from 500 to 2500 volts. Providing for direct drive of the Geiger tube for

weak samples (a few counts per sec) and a reduction ratio of 64 for high-activity materials, the unit is said to resolve pulses 20 microseconds apart. The input stage is of the Neher-Harper self-quenching type.

SCREEN WALL COUNTER

Radiation Counter Laboratories, 1451 E. 57 St., Chicago 37, Ill. The Libby Screen Wall Counter uses a "wall" of wire screening mounted inside a cylindrical metal shell. With the radiation entering the counter through the screen, the attenuating effect of a window is eliminated. A positive voltage is set up between the screen and outer shell to reduce absorption by the screen and to make the volume between the screen and the sample (mounted in a sliding cylinder) act as a collecting region for ions.



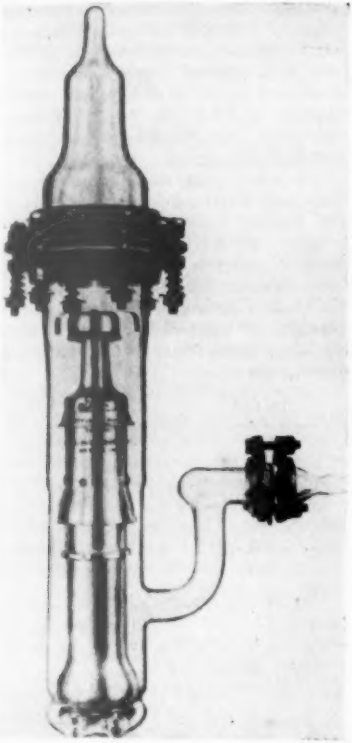
X-RAY DETECTOR

North American Philips Co., Inc., 100 E. 42 St., New York 17, N. Y. This

Geiger-counter tube has been specifically designed to be super-sensitive to X-rays. The wire at the center of the tube and the metal cylinder are electrically charged to provide a delicate circuit balance. Stray electrons, resulting from the action of cosmic rays or from earthly sources (X-ray machines, radium, etc.), will disturb the device. This disturbance causes a pulsation which is evidenced by the flash of a lamp, the click in a pair of earphones, or by pointer deflection on an electrical instrument.

OIL-DIFFUSION VACUUM PUMP

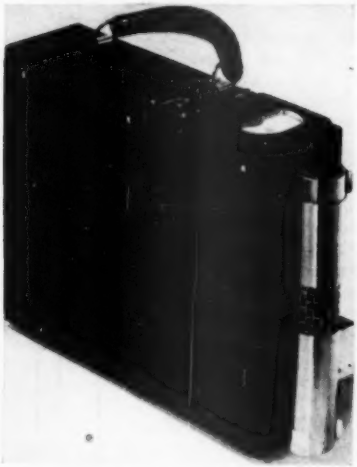
Eitel-McCullough, Inc., San Bruno, Cal. The HV-1 oil-diffusion vacuum



pump has been designed to develop an ultimate vacuum of 4×10^{-7} mm of mercury. In this pump, molecules of the gas to be evacuated diffuse into a stream of oil vapor (emitted from a jet) which is subsequently condensed and returned to the oil boiler. The gas molecules pass through three such gas vapor "jet stages" and finally reach the point where a mechanical pump removes them from the system. It is claimed that the unit can reach a pumping speed of 67 liters per sec at 4×10^{-4} to 4×10^{-6} mm of mercury.

BETA AND GAMMA RADIATION METER

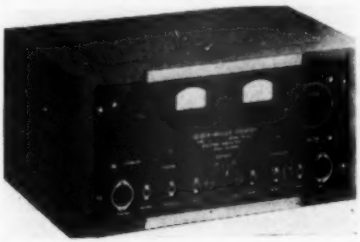
Victoreen Instrument Co., 5806 Hough Ave., Cleveland, Ohio. The portable Geiger-Müller Counter has been designed to detect individual ionizing particles. The instrument has three full-scale ranges of 0.2, 2.0 and 20.0 milliroentgens per hour measured with



gamma radiation from radium. It uses a 1½-volt flashlight cell for the filament, a miniature 67½-volt type for the plate supply, and a 900-volt battery supply for the field voltage of the Geiger tube. The latter is mounted externally in a holder which may be removed from the clip and pointed in any direction. The instrument is equipped with headphones so that audible pulses can be heard.

RADIOACTIVITY COUNTER SET

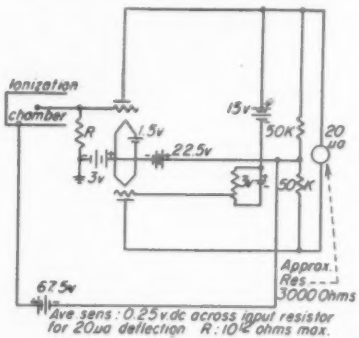
Cyclotron Specialties Co., Moraga, Cal. The apparatus includes three in-



dividual units which can be combined into one setup—the Geiger-Müller Counter, the Impulse Register and the Geiger Tube. The output of the tube, which has a mica window of 0.0006-in. thickness and 15 sq cm effective area, feeds into an external first stage (for extinguishing the counter tube and amplifying pulses) and then into the counter. The attachable register is designed to respond to 60 impulses per sec.

ELECTROMETER TRIODE

Raytheon Mfg. Co., Newton, Mass. The type CK570AX electrometer triode, developed primarily for the Atomic Energy Commission, is now available for commercial use. Requiring 12.5 milliwatts for filament power, the subminiature size tube has been designed



to measure 0.01 micromicroamperes without developing microphonic output voltage when the tube is subjected to vibration. The diagram shown is that of a recently declassified Zeus circuit commonly used for battery-operated radioactivity meters.

CARBON, NITROGEN ISOTOPES

Eastman Kodak Co., Dept. WOK, Research Laboratory, Rochester 4, N. Y. Carbon-13, the stable tracer isotope, is now being produced in concentrations of at least 60% at a rate 5 to 10 times as great as previously. Concentrations above 18% are supplied only to the Committee on Growth, National Research Council (acting for the American Cancer Society). "Permits to Purchase" must accompany laboratory purchase orders, and should be sent to Prof. D. Wright Wilson, University of Pennsylvania Medical School, Philadelphia.

C^{13} below 18% may be purchased from the Eastman laboratory. It is sold on the basis of excess C^{13} contained in 100% KCN, calculated from a chemical analysis of the solid product. Impurities are largely KOH, moisture, K_2CO_3 and hydrolysis products of the cyanide. Weight of KCN corresponding to one gram of excess C^{13} at various concentrations is:

% C^{13}	*Gm KCN*
3	263.7
5	128.5
10	56.36
15	36.12
20	26.58
40	12.97
60	8.58

Ultimately, organic compounds containing C^{13} are also expected to be available, among the first being methanol and methyl iodide.

Net prices are (no discounts):

Atom % C^{13}	*Per gm excess* C^{13}
3.0– 5.0	$100
5.1– 7.0	150
7.1–12.0	175
12.1–16.0	200
16.1–18.0	250
18.1–40.0	300*
40.1–60.0	400*

* Only through Committee on Growth.

Shipments are by express, delivery dates depending on production and priority users' requirements. Quantity supplied may be limited, and sales will be for chemical purposes, not for drug use.

Eastman has also announced that the nitrogen isotope, N^{15}, is available in the form of ammonium nitrate in which the nitrogen of the ammonium radical has been enriched by a chemical

exchange method. At present, N^{15} is available in the following concentrations (approximate) and will be sold on the basis of weight of N^{15} in excess of normal:

Atom % N^{15}	*Price/gm excess N^{15}*
5–7	$ 75
14	150
30	200
60	300

N^{15} will also be supplied in the form of potassium phthalimide, which is sold on the basis of actual nitrogen content as determined by analysis of each lot.

BORON, DEUTERIUM ISOTOPES

The Isotopes Branch of the Atomic Energy Commission (AEC) (Oak Ridge, Tenn.) has announced the availability of B^{10}. Produced by concentrating the isotope from natural boron in studies of isotope concentration, B^{10} will be shipped in the form of the solid complex, boron trifluoride-calcium fluoride. The complex contains 6.9% elemental boron, of which 96% is B^{10}. Approximately 6.5 grams of $BF_3 \cdot CaF_2$ will yield one liter of BF_3 at normal temperature and pressure (assuming 100% liberation). The boron trifluoride may be released as a gas by heating to temperatures above 260 C in a vacuum. Organic vapors and air released from the complex during heating will be present in the BF_3 and will require removal in processing material for use in neutron counters.

The price of the $BF_3 \cdot CaF_2$ complex is $2 per gm. Units of 1, 5, 10 and 50 gm can be obtained in moisture-proof containers.

Deuterium oxide and deuterium gas have also been listed by the AEC as being available through Oak Ridge. The former, packaged in 1, 2, 5, 10, and 25-gm ampules, costs $0.50 per gm for the first 100 gm and $0.30 per gm thereafter. The deuterium gas is $1.00 per liter (normal temperature and pressure) for the first 100 liters and $0.80 per liter thereafter. The gas will be shipped in standard medical gas cylinders.

STANDARDS AVAILABLE

RaD + E beta-ray standards are now available from the **National Bureau of Standards** at a cost of $10 each. These standards consist of an electrolytic deposit of lead containing RaD in the form of PbO_2 on the palladium surface of a palladium-clad silver disk $\frac{1}{16}$ in. thick. This provides saturation back-scattering, and sources compared with these standards should have a similar mounting. Silver disks identical with those used to prepare the standards are available from the Bureau of Standards at a cost of $2 each.

These standards have a total disintegration rate of 118 per sec and are suitable for calibrating bell-type, mica-window counters. Since they also emit polonium alpha particles, a foil of aluminum 0.001 in. thick must be placed between them and the counter when they are used with counters having windows thinner than about 4 mg/cm^2. Complete instructions for use of these standards in calibrating counters and preparing working standards by comparison with them are furnished with the standards. These standards can be used accurately only for calibrations involving beta-ray-emitting isotopes which have a beta-ray spectrum similar to that of RaE. The latter has an E_{max} of 1.15 Mev.

Co^{60} gamma-ray standards are also available from the Bureau of Standards. They consist of two series of solutions, flame-sealed in glass ampoules, from which they will not be removed for use. Each standard consists of 5 ml of Co^{60} solution. One series will have 1.6×10^6 disintegrations per sec per ml, and the other 1.6×10^5 disintegrations per sec per ml.

The series of radium, gamma-ray standards, consisting of 5 ml of radium solution in a flame-sealed glass ampoule, is also available. These have a radium content of 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0, 20.0, 50.0, and 100 micrograms respectively. Each solution costs $3.

For further information, correspondence should be addressed to Dr. L. F. Curtiss, National Bureau of Standards, Washington 25, D. C.

A.E.C. RADIOISOTOPES

New elements, more complete descriptions, and adjusted prices are features of A.E.C.'s. Catalog and Price List No. 2

NEW ELEMENTS have been added, more complete descriptions given, and prices adjusted in accordance with more accurate cost data in the 1947 Catalog and Price List of the Atomic Energy Commission. Elements are listed in three main groups: (1) Separated Radioisotopes, (2) Fission Products, and (3) Irradiation Units. A complete new section on "Service Irradiations" has been added to cover procedure and costs for irradiating materials furnished by the customer, in this complete revision of the original announcement of June 14, 1946, and published in *Science* **103,** 697–705, 1946.

Copies of the new catalog and recently simplified blank form (*Request for Radioisotopes,* Form 313) may be obtained by writing the United States Atomic Energy Commission, Isotopes Branch, Box E, Oak Ridge, Tenn.

NOTE—In the catalog, a *millicurie* is considered as 3.7×10^7 disintegrations per sec. When the disintegration scheme of the isotope is not known or when there is an indeterminant mixture of isotopes, absolute measurements of activity cannot be given. In such cases, the *millicurie* is defined as 3.7×10^7 beta emissions per sec in the sample. Costs to the requestor, in addition to those shown, include a handling charge of $25 per item ($10 for second and subsequent shipments on continuing orders for isotopes with half-lives under 30 days), and a deposit of $125 on returnable containers for shipment of gamma-ray emitters. Prices shown are f.o.b. Clinton Lab., Oak Ridge, Tenn.

SERVICE IRRADIATIONS

Service charge for pile-irradiation of materials furnished by the customer:

Per Month	$43.00
Per Week (or fraction)	$22.00

Prices include irradiation container and sample preparation.

Charges for irradiations for periods in excess of one month will be determined by taking the monthly rate times the number of months, plus fractions of months computed to the nearest one-fourth month.

SEPARATED RADIOISOTOPES

Catalog Item No.

S-1 CARBON 14 — $50.00 per millicurie

Half-life: 5100 y. Beta radiation: 0.145 Mev. Shipped as $BaCO_3$ in which 3–5% of the carbon atoms are radioactive. One millicurie of C^{14} will be carried in 100-175 milligrams of $BaCO_3$.

S-2 IODINE 131 — $1.70 per millicurie

Half-life: 8.0 d. Beta radiation: 0.6 Mev. Gamma radiation: 0.367 and 0.080 Mev. Carrier free in neutral or weak basic solution containing 0.3–1.0 millicuries per milliliter. Chemical analysis is furnished with each shipment. Material will meet the following specifications:

Concentration	0.5 mc/ml
pH	7–9
Total solids	less than 1 mg/ml
Te inactive	0.1 mg/ml
Te active	less than 1×10^{-4} mc/ml

S-3 PHOSPHORUS 32 — $1.10 per millicurie

Half-life: 14.3 d. Beta radiation: 1.69 Mev. Phosphate ion probably in the form of Na_2HPO_4. Chemical analysis is furnished with each shipment. Material will meet the following specifications:

Concentration	greater than 0.5 mc/ml
pH	7–9

Total solids	less than 10 mg/ml
Nonvolatile matter	less than 5 mg/ml
P (inert)	approx. 0.025 mg/mc added*
Cl	less than 5 mg/ml
Fe, Ni, Al	content such that no precipitate is present at pH 7–9

*Carrier-free material is available if desired.

S-4 SULFUR 35 — $35.00 per millicurie

Half-life: 87.1 d. Beta radiation: 0.17 Mev. Quantities of carrier-free, high specific-activity material are on hand occasionally. Routine production equipment may be in operation about June 1. Write for additional information.

FISSION PRODUCTS

Fission products are not routinely available—any order placed is subject to cancellation because of frequent changes in operating schedules.

Materials are shipped in weak acid solution in which no carrier has been added. No nonvolatile solids are present.

More complete data on the nuclear properties of fission products are given in *J. Am. Chem. Soc.* **68,** 2411–2442 (1946), or *Rev. Mod. Physics* **18,** 513–544 (1946).

TABLE 1

Catalog Item No.	*Radioisotope*	*Price per Millicurie*
I	Zr 95*, Cb 95	$ 0.67
II	Y 91	1.15
III	Ce 141*, Ce 144	1.35
IV	Ba 140	1.35
V	Sr 89*, Sr 90	1.35
VI	Pr 143, Nd 147, 61 147*, Eu 156, Eu 155	12.51
VII	Cs 137	134.70
VIII	Ru 103, Ru 106, Te 127*, Te 129	6.74

TABLE 2

(Derived from Table 1)

Catalog Item No.	*Radioisotope*	*Price Per Millicurie*
I-A	Cb 95	$ 23.09
II-A	Ru 103*, Ru 106	23.09
VI-A	Pr 143	72.16
VI-B	Nd 147	72.16
VI-C	61 147	14.43
VIII-A	Te 127*, Te 129	23.09

* Mixtures

IRRADIATION UNITS

An irradiation unit is an aluminum can in which a specified quantity of target material has been sealed and irradiated in the pile. The unit is shipped without chemical processing.

Note: Several isotopes are present in more than one unit; reference to all units in which an isotope is found in significant quantities is given opposite the name of the isotope. Requests for smaller quantities per unit may be approved but no reduction in price will be made since production costs remain the same. In those few cases where the value of the target material is appreciable, units are available in two sizes, the standard size and a 1/10 size, at a reduced price. Irradiation units are offered with the understanding that because of variations in production setup, activities may differ 50% from the quantities estimated.

Catalog Item No.	*Radioisotopes in Unit* — *Alphabetical List*	*Others Present*	*Also see Unit No.*	*Half-life*	*Radiation (Mev)* — *Beta*	*Gamma*	*Target Material* — *Compound*	*Grams*	*Estimated Quantity (mc)*	*mc/gm element (est.)*	*Price per Unit*
3A	Antimony 122		3B	2.8 d	0.81, 1.64	0.8	Sb	0.20	50	250	$ 12
		Sb 124		60 d	0.74, 2.45	1.72			1	5	
3B	Antimony 124		3A	60 d	0.74, 2.45	1.72	Sb	0.20	4	20	33
		Sb 122		2.8 d	0.81, 1.64	0.8			55	275	
3C	Antimony 125			2.7 y	0.8, 0.3	present	Sn	6.2	1.0	CF	33
		Sn 113		100 d	K, e^-	0.085			1.0	0.16	
		Sn 121		62 h	0.8	none			?	?	
		Sn 123		10 d	2.6	present			?	?	
		Sn 125 (parent of Sb 125)		9 m	?	?			?	?	
4	Argon 37			34 d	K	none	$CaCO_3$	25	0.2	CF	33
		Ca 45		180 d	0.3	none			0.8	0.1	
5A	Arsenic 76			26.8 h	1.1, 1.7, 2.7	0.57, 1.25	As_2O_3	0.06	25.0	560	12
5B	Arsenic 77		5C	40 h	0.8	none	GeO_2	1.5	0.70	CF	52
		Ge 71		11 d	0.6 beta plus	0.5			10	10	
		Ge 77		12 h	1.9	1			0.7	0.7	
5C	Arsenic 77	1/10 of Unit 5B									13
7	Barium 131	(parent of Cs 131)		12 d	K, e^-	1.2(?)	$Ba(NO_3)_2$	44	6.0	0.26	33
		Cs 131		10.2 d	K	none			9.0	CF	
		C 14		5100 y	0.145	none			0.02	CF	
9A	Bismuth 210		9B	5 d	1.17	none	Bi	24.5	10	0.4	25
		Po 210 (See Footnote No. 1)		140 d	5.298 (alpha) e^-, 0.8	0.8			0.3	CF	
9B	Bismuth 210	1/10 of Unit 9A									12
11	Bromine 82			34 h	0.465	0.547, 0.787 1.35	KBr	0.9	70	120	12
		K 42		12.4 h	3.5	none			3	1	
	Cadmium 109		12A, 12B								
12A	Cadmium 115		12B	2.8 d	1.11	0.65	Cd	1	20	20	12
		Cd 109		300 d	K	none			?	?	
		Cd 115		43 d	1.5	none			0.25	0.25	
12B	Cadmium 115		12A	43 d	1.5	0.65	Cd	1	1	1	33
		Cd 109		300 d	K	none			?	?	
		Cd 115		2.8 d	1.11	none			20	20	
13	Calcium 45		4, 69	180 d	0.3	none	Sc_2O_3	0.03	0.001	CF	33
		Sc 46		85 d	0.4	1.4			15	770	
	Carbon 14		7 (Also available in separated form)								

	Cd 109		300 d	K	none			?	?		35
	Cd 115		2.8 d	1.11	none			20	20		
13	Calcium 45		180 d	0.3	none	Sc_2O_3	0.03	0.001	CF	33	
	Sc 46	4, 69	85 d	0.4	1.4			15	770		
	Carbon 14	7 (Also available in separated form)									
15	Cerium 141		28 d	0.5	0.22	CeO_2	0.83	50	75	33	
	Ce 143 (Parent of Pr 143)		33 h	1.36	0.5			12	18		
	Pr 143		13.8 d	1.0	none			3	CF		
	Cerium 143	15									
	Cesium 131	7									
16	Cesium 134		2 y	0.75	0.8	Cs_2CO_3	0.6	20	40	34	
17	Chlorine 36		10^6 y	0.66	none	KCl	25	0.005	0.0005	33	
	K 42		12.4 h	3.5	none			200	15		
	S 35		87.1 d	0.17	none			100	CF		
	P 32		14.3 d	1.69	none			0.01	CF		
18	Chromium 51		26.5 d	K	0.32	Cr	1.1	50	50	34	
19	Cobalt 60		5.3 y	0.3	1.1, 1.3	Co_3O_4	0.9	20	30	33	
21	Copper 64		12.8 h	0.58 beta plus 0.66 beta minus	none	Cu	0.32	100	300	12	
24A	Europium 154		5-8 y	0.9	1.4	Eu_2O_3	0.25	40	180	1/40 of a unit, $84; full unit, $2,168	
24B	Europium 155 (See Footnote No. 2)	68	2 y	0.23	0.084	Sm_2O_3	0.01	0.01	CF	31	
	Sm 155 (Parent of Eu 155)		25 m								
	Sm 153		47 h	0.73	0.1, 0.57			16	2000		
28	Gallium 72		14.1 h	3.4, 0.8	0.84, 2.25	$Ga(NO_3)_3$	0.9	40	170	21	
	Germanium 71	5B, 5C									
	Germanium 77	5B, 5C									
30A	Gold 198		2.7 d	0.8	0.12, 0.44	Au	0.016	80	5000	12	
30B	Gold 199		3.3 d	1.01	0.45	Pt	0.5	10	CF	12	
	Pt 197		18 h, 3.3 d	0.72	present			7	15		
	Pt 199 (Parent of Au 199)		31 m								
31	Hafnium 181 (See Footnote No. 2)		46 d	present	?	Hf_2O_3	0.9	50	60	31	
35	Element 61 147 (See Footnote No. 2)		4 y	0.3	none	Nd_2O_3	0.01	0.001	CF	31	
	61 149		2 d					0.1	CF		
	Nd 147		11 d	0.4, 0.9	0.6			0.03	3.5		
	Nd 149 (Parent of 61 149)		1.8 h					?			
	Element 61 149	35									
36A	Indium 114	36B	48 d	I.T., e^-, 2.0	0.19	$In(NO_3)_3$	0.36	10	70	89	
36B	Indium 114	1/10 of Unit 36A								36	
37	Iodine 131		8 d	0.6	0.367, 0.080	Te	50	100	CF	33	
	Te 127		90 d	I.T., e^-, 0.7 9.3 h isomer	0.086			10	0.20		
	Te 129		32 d	I.T., e^-, 1.8 70 m isomer	0.102, 0.3, 0.8			8	0.16		
	Te 131 (Parent of I 131)		30 h	I.T.	0.177			10	0.20		
	Iodine 131 Also available in separated form										
38A	Iridium 192	38B	70 d	Present	0.3, 0.4	IrO_2	0.22	40	210	35	
	Ir 194		19 h	2.2	1.35			200	1050		

IRRADIATION UNITS (Continued)

Item No.	Radioisotopes in Unit: Alphabetical List	Others Present	Also see Unit No.	Half-life	Radiation (Mev): Beta	Gamma	Target Material: Compound	Grams	Estimated Quantity (mc)	mc/gm element (est.)	Price per Unit
38B	Iridium 194		38A	19 h	2.2	1.35	IrO_2	0.05	40	930	$12
		Ir 192		70 d	Present	0.3, 0.4			3	70	
	Iron 55		39								
39	Iron 59			44 d	0.26, 0.46	1.1, 1.3	Fe	17	1	0.06	33
		Fe 55		4 y	K				0.5	0.03	
41	Lanthanum 140			40 h	1.4 (90 %)						
					2.2 (10 %)	1.63	La_2O_3	0.09	40	525	12
47A	Mercury 197		47B	64 h	K, e^-	0.075					
				25 h	K, e^-	0.13, 0.16	$Hg(NO_3)_2$	20	95	8	12
		Hg 203, 205		51.5 d	0.3	0.28			40	3	
47B	Mercury 203, 205		47A	51.5 d	0.3	0.28	$Hg(NO_3)_2$	20	135	11	33
		Hg 197		64 h	K, e^-	0.075			110	9	
				25 h	K, e^-	0.13, 0.16					
48	Molybdenum 99	(Parent of Tc 99)	77	67 h	1.3	0.24, 0.75	Mo_2O_3	10	40	5	12
		Tc 99		10^6 y	0.3	none			Very small	CF	
	Neodymium 147		35								
	Neodymium 149		35								
51	Nickel 59			15 y	K		Ni	10	1	0.1	33
					50 KV particle						
	Osmium 185		53								
	Osmium 191		53								
53	Osmium 193			17 d	0.35	present	Os	0.55	40	73	42
		Os 185		80 d	K	none			?		
		Os 191		32 h	1.5	present			18	33	
55	Palladium 103		72B	17 d	K	none	Pd	1	Undetermined		33
		Ag 111		7.5 d	0.8	none			10	CF	
56A	Phosphorus 32		17, 56B, 75	14.3 d	1.69	none	S	2000	500	CF	323
		S 35		87.1 d	0.17	none			80	0.04	
56B	Phosphorus 32		17, 56A, 75	14.3 d	1.69	none	KH_2PO_4	31	350	50	33
		K 42		12.4 h	3.50	none			140	155	
	Phosphorus 32	Also available in separated form									
	Platinum 197		30B								
	Platinum 199		30B								
	Polonium 210		9A, 9B								
59	Potassium 42		11, 17, 56B	12.4 h	3.5	none	K_2CO_3	22	130	10	12
60	Praseodymium 142			19.3 h	2.14	1.9	Pr_2O_3	0.085	40	550	13
	Praseodymium 143		15								
64	Rhenium 186			90 h	1.0	none	Re	0.05	75	1500	12
		Re 188		18 h	2.5	0.8			120	2400	
	Rhenium 188		64								
65A	Rhodium 105		65B, 67A	36 h	0.5	0.3	RuO_2	5	10	CF	54
		Tc 97		90 d	K, e^-	0.97			0.3	CF	
		Ru 97 (Parent of Tc 97)		2.8 d	K, e^-	none			8	2	
		Ru 103		42 d	0.2 (95 %)	0.56			3	1	
					0.8 (5 %)						
65B	Rhodium 105		1/10 of Unit 65A								13
66A	Rubidium 86		66B	19.5 d	1.60	none	Rb_2CO_3	6.5	100	20	62
66B	Rubidium 86		1/10 of Unit 66A								34
67A	Ruthenium 97		65A, 65B, 67B	2.8 d	K, e^-	none	RuO_2	5.0	10	2	62

	Ru 103		42 d	0.2 (95%) 0.8 (5%)	0.56			3	1	
65B	Rhodium 105	$\frac{1}{10}$ of Unit 65A								13
66A	Rubidium 86	66B	19.5 d	1.60	none	Rb_2CO_3	6.5	100	20	62
66B	Rubidium 86	$\frac{1}{10}$ of Unit 66A								34
67A	Ruthenium 97	65A, 65B, 67B	2.8 d	K, e^-	none	RuO_3	5.0	10	3	68
	Tc 97		90 d	K, e^-	0.97			1	CF	
	Ru 103		42 d	0.2 (95%) 0.8 (5%)	0.56			10	3	
	Rh 105		36 h	0.5	0.3			10	CF	
67B	Ruthenium 97	$\frac{1}{10}$ of Unit 67A								34
	Ruthenium 103	65A, 65B, 67A, 67B								
68	Samarium 153 (See Footnote No. 2)	24B	47 h	0.73	0.1, 0.57	Sm_2O_3	0.01	16	2000	9
	Eu 155		2 y	0.23	0.084			0.01	CF	
	Sm 155 (Parent of Eu 155)		25 m							
69	Scandium 46	13, 84	85 d	0.4	1.4	Sc_2O_3	0.002	1	770	33
	Ca 45		180 d	0.3	none			0.0001	CF	
70	Selenium 75		125 d	K, e^-	0.18, 0.35	Se	20	65	3.3	33
72A	Silver 108, 110		225 d	1.3	0.6, 0.9	$AgNO_3$	7.1	35	8	33
72B	Silver 111	55	7.5 d	0.8	none	Pd	1	10	CF	15
	Pd 103		17 d	K	none			?	?	
73	Sodium 24		14.8 h	1.4	1.4, 2.8	Na_2CO_3	0.9	20	130	12
74	Strontium 89		53 d	1.5	none	$Sr(NO_3)_2$	33	1.5	0.11	33
75	Sulfur 35	17, 56A	87.1 d	0.17	none	S	25	1.0	0.04	33
	P 32		14.3 d	1.69	none			6.0	CF	
76	Tantalum 182		97 d	0.53	1.13, 1.22	TaO_3	0.22	40	215	33
	Technitium 97	65A, 65B, 67A, 67B								
77	Technitium 99	48	10^6 y	0.3	none	Mo_2O_3	10	0.00001	15	33
	Mo 99		67 h	1.3	0.24, 0.75			Undetermined		
	Tellurium 127	37								
	Tellurium 129	37								
	Tellurium 131	37								
80	Thallium 206		2.7 y	0.58	none	$Tl(NO_3)_3$	10	7	1.2	33
	Tin 113	3C								
	Tin 121	3C								
	Tin 123	3C								
84	Titanium 51		72 d	0.36	1.0	TiO_2	19	1	0.9	33
	Sc 46-47-48 probable									
85A	Tungsten 185	85B	77 d	0.55	none	WO_3	1.8	10	7	33
	W 187		24 h	1.4	0.086 to 0.94			500	350	
85B	Tungsten 187	85A	24 h	1.4	0.086 to 0.94	WO_3	0.12	40	420	12
	W 185		77 d	0.55	none			0.2	21	
90	Yttrium 90		65 h	2.5	none	Y_2O_3	1.1	100	115	33
91	Zinc 65		250 d	0.4 beta plus (1%) K, e^- (99%)	1.14	Zn	8	20	2.5	33
	Zn 69		13.8 h	I.T., 1.0	0.439			60	7.5	
	Zinc 69	91								
92	Zirconium 95		65 d	1.0, 0.39	0.73	$Zr(OH)_4$	22	12	9	12

(1) Maximum quantity 25 days after removal from pile.

(2) Target material to be furnished by requester.

INDUSTRY AND NUCLEONICS

THE PRINCIPAL RESOURCE of the United States in the development of the atomic bomb was the tradition of education and aggressive industry.

When the nation was called upon to take the ideas germinating throughout the world since the Curies discovered radium, to develop those ideas in laboratories, and to translate them into production-scale plants of unprecedented dimensions, the brains and energy came from all walks of life and elements of industry.

We had strong academic research institutions, we had aggressive engineering talent, we had sufficient managerial experience, and we had construction technique, skilled workmen and productive capacity. We did not plan it with nuclear fission in mind.

Today, however, believing atomic energy and the processes involving nuclear reactions hold great promise for the future of mankind, American industry wants to plan, and plan intelligently, for its part in what is almost sure to be an historic change in the course of civilization. Industry wants to know when and how it can prepare for its role, when it should invest in training men—managers, economists, engineers, specialists in many fields—in the potentially profitable business of supplying materials, equipment, instruments and services to a field of industrial endeavor whose limits cannot be seen.

Training Course Content

Both industry and education would like to know what such training should cover. Industry wants to know how to prepare for producing the materials it will be called upon to provide for the nuclear industry.

These questions cannot be easily answered. They cannot and should not be answered in bureaucratic fashion. Certainly the United States Atomic Energy Commission should not invade the prerogatives or prejudice the initiative of industry management. Nor should the Commission ask the educational institutions of the nation—upon which we depend largely for our progress in fundamental science—to reshape their curricula in accord with some fancied standard which cannot be developed through any process other than crystal-ball gazing.

The foundation, the framework, and the objectives of the United States Atomic Energy Program rest on the Atomic Energy Act of 1946. This Act reflects two points of view of Congress, first, that the whole subject of atomic energy is in a preliminary state of development and any legislation will "necessarily be subject to revision from time to time" and, second, that "this new source of energy will cause profound changes in our present way of life."

"In other words," as Commissioner Sumner T. Pike said recently, "we don't know quite what we have here but we do know that it is important."

Nonmilitary Applications

We have proved the military applications of atomic energy, but we have yet to demonstrate any commercial use, or even to see it clearly. The character of the wartime development required complete secrecy and the importance to the national security of atomic energy necessitates government monopoly. But Congress recognized the nonmilitary potential of atomic energy and the need for extensive and costly research before these other applications could be exploited.

Congress directed that, when any commercial use of atomic energy approaches practicability, the Commission will report to the President all pertinent facts and an estimate of the effect of the new use on industry with recommendations for legislation. The Presi-

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General Manager, United States Atomic Energy Commission

dent is to transmit this information to the Congress, with his own recommendations. There can be no licensing of such a development until the Congress has had 90 days in which to consider the problem.

The current objectives of the United States Atomic Energy Commission were emphasized in the remarks of Chairman Lilienthal before Committee No. 2 of the United Nations Atomic Energy Commission on June 2, 1947, in response to the invitation of the United States Representative. The Chairman stated that until there are adequate international safeguards satisfactory to the nations of the world " . . . the purpose of the United States Atomic Energy Commission is to maintain, and, indeed, increase the preeminence of the United States of America in the field of the development of atomic energy and atomic weapons."

Extensive Research

Such a purpose does not mean that development of military applications of atomic energy precludes other applications, principally because, until almost the final point of adaptation, the work does not separate into any such categories. It does mean, however, that both fundamental and applied research must be supported with all the resources at our command; that thousands of scientists, engineers, technicians and management personnel must be trained; that additional, physical facilities of all types must be provided as rapidly as possible; that operations must be unhampered by considerations and restrictions other than those inherent in such a scientific, engineering and industrial undertaking. and that the people of the United States must be continuously aware of their stake in this project.

Industrial and academic organizations are today carrying on the work of the United States Atomic Energy Program as contract-operators of government facilities of all types and as contractors in their own facilities on specific research and development contracts. They are acquiring the knowledge and techniques which need to be tested, tried, extended, and expanded if the nation is to have a strong atomic energy program.

There are critical shortages of men trained in the nuclear sciences. Men qualified to work with the products of nuclear processes, radioisotopes, are needed in the fields of metallurgy, medicine, biology, agriculture, petroleum, and scores of lesser segments of chemical engineering.

Broadening of Program

As rapidly as the facilities for the study of the effects of neutron bombardment become more available—for both equipment and structures required in atomic energy—more industries will have a part in the development of this knowledge into practical applications. And as rapidly as experience in the operation of reactors justifies, and as the design and materials for reactors are tested and proved, the United States Atomic Energy program will be broadened still further to utilize the nation's engineering and industrial resources to the fullest possible extent.

This must go forward as rapidly as possible. The will of the people of the United States, as written into the Atomic Energy Act of 1946 by the Congress, is " . . . subject at all times to the paramount objective of assuring the common defense and security, the development and utilization of atomic energy shall, so far as practicable, be directed toward improving the public welfare, increasing the standard of living, strengthening free competition in private enterprise, and promoting world peace."

MANHATTAN DISTRICT DOCUMENTS

DECLASSIFIED PAPERS* released since April 8, 1946, available to us, have been arranged by code number by the editors of NUCLEONICS. Appearing below is the first portion of the list. In its second semi-annual report to Congress, the Atomic Energy Commission pointed out that the technical articles are being cleared for public release at the rate of 100 a month. Additional titles will appear in future issues of NUCLEONICS.

Listed with the name of the paper are its author(s), MDDC (Manhattan District Declassification Code) number, and date of declassification.

Mass Spectrometer for Leak Detection. A. O. Nier, C. M. Stevens, A. Hustralid, T. A. Abbott. MDDC 5 (4/8/46)

The Neutron-Proton and Neutron-Carbon Scattering Cross Sections for Fast Neutrons. C. L. Bailey, V. E. Bennett, T. Bergstrahl, R. G. Nucholls, H. T. Richards, J. H. Williams. MDDC 6 (7/9/46)

Thick Target Yields with Deutron-Proton Reactions. E. C. Barker. MDDC 7 (5/16/46)

On the Disintegration of Nitrogen by Fast Neutrons. H. H. Barschall, M. E. Battat. MDDC 8 (5/21/46)

Scattering of Fast Neutrons by Boron. H. H. Barschall, M. E. Battat, W. C. Bright. MDDC 9 (6/6/46)

Neutrons From $C^{12} + D$. W. E. Bennett, H. T. Richards. MDDC 10 (6/6/46)

On the Existence of a Resonance Absorption of Neutrons in Graphite. Seymour Bernstein. MDDC 11 (6/14/46)

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The Multi-Channel Pulse Analyzer. A. Ghiorse, B. Weissbourd, H. Robinson. MDDC 23 (6/14/46)

A Method for Measuring Half Lives. A. Graves, R. Walker. MDDC 24 (5/17/46)

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Joule-Thomson Effects in Deuterium at Liquid Air and at Room Temperatures. H. L. Johnston, C. A. Swanson, H. E. Wirth. MDDC 30 (4/8/46)

* Inquiries regarding these documents may be referred to the Information Branch, Research Division, Atomic Energy Commission, P. O. Box E, Oak Ridge, Tennessee.

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A Manual on the Measurement of Radioactivity. A. H. Jaffey, et al. MDDC 388 (10/16/46)

Preparation of a Compact Radioyttrium Gamma-Ray Source. M. Kahn. MDDC 389 (10/24/46)

The Preparation of Thin Films of Thorium Oxide. M. Kahn. MDDC 390 (10/22/46).

Some Pre-war Nucleonics Literature

A survey of "pre-atomic age" literature shows nuclear science began 51 years ago with Becquerel's discovery of natural radioactivity, but applied nuclear physics did not come into its own until Curie and Joliot announced artificial radioactivity

By WALTER M. DeCEW, Technical Editor

ALTHOUGH APPLICATIONS of nuclear physics have grown spectacularly in recent years, a vast amount of valuable nucleonic literature dates back to 1930 and before. A reading of "pre-atomic age" books and reviews will bring this new technology into proper perspective for the non-specialist and student and provide a firm foundation for profitable use of latest advances in nucleonics.

The literature of nuclear science actually began 51 years ago with Vol. 122, 1896 *Comptes Rendus*, in which H. Becquerel announced his discovery of radioactivity. During the following few decades, however, nuclear physics was confined almost exclusively to natural radioactivity. It was not until the discovery of artificial radioactivity by I. Curie and F. Joliot, announced in Vol. 198, 1934 *Comptes Rendus*, that the rapidly expanding usefulness of nuclear phenomena came to be reflected throughout the journals of chemistry, metallurgy, radiology, geology, biology, and medicine.

Standard Radioactivity Book

The vast amount of information relating to natural radioactive elements, and accumulated before the advent of artificial radioactivity, is fully presented and referenced in *Radiations from Radioactive Substances* by E. Rutherford, J. Chadwick, and C. D. Ellis (The Macmillan Co., New York, 1930). This is still the standard English work on radioactivity.

As the nucleonics of today was the fundamental nuclear physics of yesterday, a logical starting place for the study of modern nucleonics would be the report, "Nuclear Physics," which appeared in three parts in the *Reviews of Modern Physics* during 1936 and 1937. Part A (April, 1936) of the report, "Stationary States of Nuclei," written by H. A. Bethe and R. F. Bacher, covers such topics as the fundamental properties of nuclei, qualitative arguments about nuclear forces, beta-disintegration and nuclear forces, and nuclear moments. Part A has been reprinted with Parts B (April, 1937) and C (July, 1937) by the American Institute of Physics (price, total: $4.50).

Part B, "Nuclear Dynamics, Theoretical," by H. A. Bethe, deals with the distribution and widths of nuclear-energy levels, nuclear resonance phenomena, nuclear scattering, capture, and disintegration, gamma rays, and other related subjects. Written at one of the most exciting stages in the development of nuclear theory, this paper presents a revealing picture of our modern concepts of nuclear phenomena in process of formation. One recognizes concepts and methods of attack now discarded, as well as problems still unsolved.

Part C, "Nuclear Dynamics, Experimental," by M. S. Livingston and H. A. Bethe, covers methods which had been most productive of experimental data up to July, 1937, the basic-range energy relations and other still-valid formulas for evaluation of experiments, description and classification of nuclear reactions, and other basic experimental facts that form the foundation for current nuclear technology.

One of the best recommendations for this classic 1936–1937 review of nuclear physics is the voluminous reference to the original sources of practically all the important work in fundamental nuclear research during the preceding decade.

One of today's best-known applications of nuclear physics is the use of tracer isotopes which, as tools for unraveling extremely complex reactions, processes and systems, have so broadened chemistry and the life sciences that one can anticipate almost limitless advances. As early as 1913, however, this method was being applied to chemical problems by F. A. Paneth and G. Hevesy. During the years that followed, they and their students made extensive investigations of the mechanism of exchange reactions, of oxidation-reduction couples, self-diffusion in lead, and many other problems in chemistry and biology. This early work, limited to the naturally radioactive elements, is described by Paneth in *Radio-elements as Indicators* (McGraw-Hill Book Company, Inc., New York, 1928).

Thus the groundwork and fundamental principles of isotope tracer technique were all worked out long before 1930. However, the use of isotopes as tracers did not become a major application of nuclear physics until the middle and late 1930's. Only then were tracer isotopes of most of the chemical elements discovered and made available in cyclotron quantities, together with the instruments for detecting them. Today, about 450 isotopes of the 96 known chemical elements have been made available.

Tracer Applications

In 1940, there appeared several comprehensive and authoritative reviews of isotope tracer applications in chemistry and biology. J. R. Loofbourow surveyed biochemical and physiological tracer work in *Reviews of Modern Physics*, Vol. 12, 1940. Extensive references are included, more than 300 publications in physiology alone being cited.

Chemical uses of isotope tracers were reviewed by G. T. Seaborg in an 86-page article for the August, 1940, *Chemical Reviews* (Vol. 27, No. 1). In this survey, Seaborg mentions more than 500 publications, most of them different from those in the article by Loofbourow. Detailed and realistic analyses of chemical problems contained in this article make it valuable to anyone with a technical interest in the chemical or metallurgical industries.

One of the pioneers and foremost leaders in the application of tracer techniques to biochemical problems, G. Hevesy, gave a sophisticated analysis of this phase of nucleonics under the title "Applications of Radioactive Indicators in Biology" which appeared in the *Annual Reviews of Biochemistry* for 1940. It was written from the point of view of the biochemist and discussed the general and specific types of biochemical problems then believed to be most accessible by the radiotracer approach.

Reference Books

Two valuable reference books embodying much of the research of the period covered in the above reviews are *A Manual of Radioactivity* by G. Hevesy and F. A. Paneth (Oxford University Press, London, 1938) and *Applied Radiochemistry* by Otto Hahn (Cornell University Press, Ithaca, N. Y., 1939). Both books were written from the chemist's point of view, but Hahn's gives considerable attention to metallurgical problems.

The entire April, 1941, *Journal of Applied Physics* was devoted to applied nuclear physics (now called *nucleonics*) because of the field's great progress in the preceding few years. In it are abstracts from the 1940 Massachusetts Institute of Technology conference on applied nuclear physics, a review of the field by Robley D. Evans entitled "Applied Nuclear Physics," a discussion of the separation and use of stable isotopes by Harold C. Urey, and "Biological Effects of Ionizing Radiations" by G. Failla. Altogether, more than 100 papers were presented. They dealt with applications of all types of nuclear

phenomena to biology, chemistry, radiology, metallurgy, geology, and medicine.

The titles of a few of the conference papers abstracted in the *Journal of Applied Physics* indicate the advancement of nucleonics in 1941. Representative papers were: "Use of Isotope Tracers in the Study of the Composition of Proteins," "Tracer Studies in Metallurgy," "Measurement of Vapor Pressures and Solubilities by Radiochemical Methods," "Chemical Effects of Nuclear Transitions," "The Permeability of Cells to Cations," "Neutron Beam Therapy," "Radiography with Gamma-rays," "Neutron Studies of Order in Fe-Ni Alloys," and "Outlook for Use of Neutron Scattering in Studying Ferromagnetic Substances."

At the start of World War II, there were available a large number of up-to-date text and reference books on fundamental and applied nuclear physics, particularly in German and other European languages. Of the latter, mention should be made of *Einfuhrung in die Kernphysik* by Wolfgang Reizler (Bibliographisches Inst. A. G., Leipzig, 1937). In the best tradition of German textbooks, it leads to an intuitive understanding of fundamental concepts without sacrificing rigor or comprehensiveness.

1942 Nucleonics

In English, *Applied Nuclear Physics* by Ernest Pollard and W. L. Davidson (John Wiley & Son, Inc., New York 1942) presented the essential facts and techniques of 1942 nucleonics in such a way as to make it of unique value to the growing army of chemists, biologists, physicians and engineers then entering this field. It was not intended primarily as a reference book, but rather as one to be read for description and explanation. Discussions of the properties of nuclear radiations, detection of nuclear particles, nuclear reactions, and radioactivity theory give the reader a good start in comprehending the physics of the atomic nucleus. Two excellent chapters are devoted to the technique and applications of radioisotope research, and one to stable isotopes and their application. Final chapters touch on the 1942 status of nuclear theory and nuclear fission.

Elements of Nuclear Physics by France Rasetti (Prentice-Hall, Inc., New York, 1936) covers much the same ground, though less comprehensively, as the 1936–1937 *Reviews of Modern Physics* report. Quite theoretical, this book gives the reader a taste of the quantum mechanical ideas which form the core of modern nuclear theory. It may be well to emphasize that one cannot gain a working knowledge of fundamental nuclear physics without a thorough preliminary grounding in quantum mechanics because the interactions of nuclear particles cannot be described in terms of classical Newtonian mechanics. There are many excellent introductory and advanced books on this subject, however.

Nuclear Physics Fundamentals

The "Particles" of Modern Physics by J. D. Stranathan (The Blakiston Company, Philadelphia, Pa., 1942) presents the experimental evidence underlying our present concepts of the nucleus in such a thorough and easily understandable way that study of this book should dissipate much of the amazement and unreality surrounding the spectacular release of "atomic energy." Written at the advanced undergraduate level, this 571-page text explains the fundamentals of nuclear physics as satisfactorily as it can be done without the aid of mathematics.

An Introduction to Nuclear Physics by N. Feather (Cambridge University Press, New York, 1936) has long been a standard and widely read nuclear physics text, and could still be profitably read in 1947. Until many more nuclear physics books are written, books such as this and the others described will not lose their value.

An up-to-date picture of wartime and postwar progress in nucleonics will be found in the articles, bibliographic references, and book reviews appearing in this and subsequent issues of NUCLEONICS.

NUCLEONIC EVENTS

CARNEGIE TECH BUILDS CYCLOTRON

The Carnegie Institute of Technology is designing a large, frequency-modulated cyclotron. Experimental and theoretical work is now going on to determine the best means to construct a magnet for this machine to obtain the highest-energy protons with a given amount of steel, copper and power. A model of the Dee and oscillator has been set up in full scale in the Dept. of Electrical Engineering. The present plans call for construction to start this winter on a machine with about 130-in. diameter pole pieces to produce protons with energies in excess of 200 Mev. Two new buildings have been designed, one to house the cyclotron itself and one for auxiliary laboratories.

Carnegie is also carrying on experimental work in cooperation with the University of Pittsburgh in the scattering of high-energy neutrons by protons and the slowing down and absorption of neutrons by various shielding materials which will be of interest for the new cyclotron.

NEW PARTICLES DISCOVERED

The cosmic ray research expeditions of the Soviet Academy of Sciences, which continue their activity at Mt. Alagez in the Caucasus and in the Central Asian Pamir, have announced the discovery of new types of elementary particles with special properties. It is claimed that these particles, discovered in large quantity, have a mass approximately 1,000 times greater than the mass of the electron. Numerous facts now established point to the existence of particles without charge, that most effectively split the atomic nuclei.

Research in nuclear reactions carried out by the Soviet Radium Institute has revealed that the interaction between accelerated particles of helium with atomic weight 3, and the nuclei of various elements such as bromium or silver, leads to the recovery of a neutron which is a component of the nucleus of one of the above elements, and results in the formation of helium nuclei with atomic weight 4.

RADIATION CHEMISTRY SYMPOSIUM HELD

The Symposium on Radiation Chemistry and Photochemistry held this summer at the University of Notre Dame was the first of its kind. The meeting, heavily attended by representatives of the United States, England and Canada, gave considerable attention to the distribution of energy in radiation-chemical primary processes. Chairman of the Symposium and Secretary of the Sponsoring Committee, respectively, were Dr. S. C. Lind of the University of Minnesota and Dr. Milton Burton of Notre Dame.

Among the papers presented were "Radiation Chemistry of Aqueous Solutions," by A. O. Allen, Monsanto Chemical Co.; "Transformation of Organic Substances by Alpha Particles and Deuterons," by Irving A. Breger, Massachusetts Institute of Technology; "Free Radical Determination with the Mass Spectrometer," by George C. Eltenton, Shell Oil Co.; "Reactions of Bromine Atoms Produced by Isomeric Nuclear Transition, by the Neutron-Gamma Reaction and by Light Absorption," by John E. Willard, University of Wisconsin; "Metastable Ions," by J. A. Hipple, National Bureau of Standards; "Radiation Chemistry of Geiger Counter Tubes," by Paul Weisz, Socony-Vacuum Oil Co.; "Chemical Effects Accompanying Nuclear Decay

by β-Emission," by I. H. Davies, University of Chicago; and "An Interpretation of the Behavior of Some Organic Compounds," by Dr. Burton.

Abstracts of some of these papers will appear in the October issue of NUCLEONICS.

KELLEX REPORTS ON ACTIVITIES

In its annual "Report to the Director," the Kellex Corp. has outlined its future plans "as the only company exclusively engaged in the field of nuclear energy." At Oak Ridge, Kellex will engineer a new type, experimental nuclear reactor, including chemical and metallurgical processes. The company is working with Johns Hopkins University on the development of guided missiles at Silver Spring, Md. Also included in the report is a review of the work done at the K-25 and K-27 diffusion plants at Oak Ridge.

SOUTH AFRICAN DESIGNS PARTICLE ACCELERATOR

Costing about one tenth or less than a cyclotron of the same power, apparatus for atom-splitting experiments has been evolved by Alva Archer, an electrical engineer at the University of Witwatersrand (Johannesburg), working under the direction of Arthur Bleksley, senior lecturer in the Dept. of Applied Mathematics at the university.

The prototype model is now being designed and is expected to produce about 40,000,000 volts. Working on the synchrotron principle, the accelerator will use a ring-shaped magnet giving to the charged particles a magnetic field that will increase the orbit radius. The field in the immediate vicinity of the orbit is modified to provide axial and radial stability, a modification which expands with the orbit.

A.E.C. REPORT

Copies of the second "Semi-annual Report to Congress" by the Atomic Energy Commission can be obtained (free of charge) by writing to Office of Information, U. S. Atomic Energy Commission, 1901 Constitution Ave., Washington 25, D. C.

NUCLEAR NEWSMAKERS

Dr. Joseph J. Burbage has been promoted to the position of Assistant Laboratory Director of Units 3, 4, and 5 of the Central Research Department at the Dayton, Ohio, atomic research laboratory, Monsanto Chemical Co.

Cleveland Norcross, formerly Executive Secretary of the Office of Scientific Research and Development, has been appointed to a newly created post, Assistant Director, in the American Institute of Physics.

Dr. Eugene P. Wigner and **Dr. L. W. Nordheim** have resigned from their positions as Director of Research and Development and Director of the Physics Division, respectively, at the Clinton Laboratories in Oak Ridge, Tenn. Dr. Wigner has returned to Princeton University and Dr. Nordheim to Duke University.

Dr. Edward U. Condon, Director of the National Bureau of Standards, and **Dr. Detlev W. Bronk,** Chairman of the National Research Council, have been appointed members of the Scientific Advisory Committee of the Brookhaven National Laboratory.

A medical board of review to advise the U. S. Atomic Energy Commission on nuclear research in the medical and biological fields has been set up. The following have been appointed to this board: **Dr. Robert P. Loeb** (Chief, Division of Medicine, Presbyterian Hospital, New York) chairman; **Dr. Detlev W. Bronk** (Chief Radiologist, University Hospital, Philadelphia); **Dr. Wallace O. Fenn** (Professor of Biology, University of Rochester Medical School, Rochester, N. Y.); **Dr. Herbert S. Gasser** (Physiologist, Rockefeller Institute for Medical Research, New York); **Dr. Ernest W. Goodpasture** (Vanderbilt University School of Medicine, Nashville, Tenn.); **Dr. Alan**

Gregg (Director for Medical Sciences, Rockefeller Foundation, New York); and **Dr. A. Baird Hastings** (Harvard Medical School, Cambridge, Mass.).

Capt. L. McKee, USN, and **Capt. A. G. Mumma,** USN, have been named Coordinator and Deputy Coordinator for Nuclear Matters, respectively, in the nuclear energy organization established by the Navy Bureau of Ships. Capt. Mumma also heads the Nuclear Power Section. **Capt. W. S. Maxwell,** USN, and **Comdr. J. M. Waters,** USN, are in charge, respectively, of the Radiological Safety Section and the Atomic Warfare Defense Section.

Robert D. Conrad, Captain USN retired, is engaged in administration and planning in his new position as Assistant Director of Brookhaven National Laboratory. He was formerly head of the Progress and Planning Section of the Office of the Coordinator of Research and Development (Office of the Secretary of the Navy).

Dr. Herbert S. Gasser, director of the Rockefeller Institute for Medical Research, New York, has been awarded an honorary doctor of science degree by Oxford University.

Werner Heisenberg, winner of the Nobel Physics Award in 1932, has resigned from the staff of Göttingen University in Germany to join the faculty of the University of Buenos Aires in Argentina.

MEETINGS

American Chemical Society—New York, N. Y., Sept. 15–19.

American Institute of Electrical Engineers—Middle Eastern District meeting, Dayton, O., Sept. 23–25.

Institute of Radio Engineers—West Coast Convention, Palace Hotel, Palo Alto, Cal., Sept. 24–26.

American Institute of Chemical Engineers—Regional Meeting, Hotel Statler, Buffalo, N. Y., Sept. 29–Oct. 1.

Electrochemical Society—Fall Congress, Copley-Plaza Hotel, Boston, Mass., Oct. 15–18.

National Metal Congress and Exposition—International Amphitheater, Chicago, Ill., Oct. 18–24.

American Society for Metals—Chicago, Ill., Oct. 20–24.

American Standards Association—Annual Meeting, New York, N. Y., Oct. 21–23.

Pacific Chemical Exposition and Pacific Industrial Conference, sponsored by Cal. section of American Chemical Society, Civic Auditorium, San Francisco, Cal., Oct. 21–25.

Optical Society of America—Cincinnati, O., Oct. 23–25.

American Mathematical Society—New York, N. Y., Oct. 25.

National Electronics Conference—Edgewater Beach Hotel, Chicago, Ill., Oct. 25.

American Institute of Electrical Engineering—Midwest General Meeting, Chicago, Ill., Nov. 3–7.

American Physical Society—Houston, Tex., Nov. 28–29.

American Society of Mechanical Engineers—Annual Meeting, Atlantic City, N. J., Dec. 1–5.

Exposition of Chemical Industries—Grand Central Palace, New York, N. Y., Dec. 1–6.

American Association for the Advancement of Science—Chicago, Ill., Dec. 26–31.

American Physical Society—Chicago, Ill., Dec. 29–31.

Canada's Nuclear Reactor

"The Chalk River (Ontario) pile is an original design. While certain basic nuclear physical data was pooled by Canada, Great Britain and the United States, only a very limited amount of data on a different type of pile from that at Chalk River was available to Canada. To all intents and purposes, the complete design of the Chalk River plant, except for the basic nuclear physical data, was originated and developed and the plant was brought into being by the efforts of Canadian and British engineers." . . . *C. H. Jackson* (*Chief Engineer, Special Projects Dept., Defense Industries Ltd*), Engineering Journal, *June*, 1947.

ABSTRACTS

CHEMICAL PUBLICATIONS

The synthesis of 1,2,5,6-dibenzanthracene labeled in the 9-position with carbon-14, C. Heidelberger, P. Brewer, W. Dauben (Univ. of Calif., Berkeley), *J. Am. Chem. Soc.* **69,** 1389–91 (1947). β-naphthoic acid, prepared in 73% yield by carbonation of the Grignard reagent from β-bromonaphthalene with $C^{14}O_2$, was converted to the acid chloride with $SOCl_2$ and allowed to react with β-methylnaphthalene and $AlCl_3$. The resulting ketone, 1-(2-naphthoyl)-2-methylnaphthalene (*I*), was pyrolyzed at 435° to give 1,2,5,6-dibenzanthracene (*II*). The over-all yield of *II* was 11% based on the C^*O_2. A study of the Elbs reaction of *I* was carried out by pyrolyzing *I* for various lengths of time. Volatile by-products were swept out, combusted, and the carbon dioxide precipitated as barium carbonate. The latter was found to be highly radioactive, indicating that some of the extensive decomposition which occurs in the Elbs reaction involves volatilization of the carbonyl carbon atom. Optimum yields were obtained for reaction times of 3 hrs. or more.

Synthesis of carbon radioactive methyl iodide and methanol from carbon dioxide, B. Tolbert (Univ. of Calif., Berkeley), *J. Am. Chem. Soc.* **69,** 1529–31 (1947). Carbon radioactive CH_3I and CH_3OH were prepared on a 25-millimole scale from $C^{14}O_2$. C^*O_2, prepared by the action of H_2SO_4 on BaC^*O_3, was reduced by H_2 with $KCuAl_2O_3$ as a catalyst in a microbomb at 450 atm. pressure and 285°. The yield depends greatly upon the pressure and the reaction time; 450 atm. and 6 hrs., respectively, gave the optimum yields. The C^*H_3OH was converted to C^*H_3I by treating with I_2, red P_4 and H_2O. The yield of C^*H_3I was 81–86% based on the C^*O_2 used. Special techniques are necessary to process small quantities of volatile organic compounds. All operations were carried out in a closed system evacuated to at least 10 microns. Quantitative transfers were made by distilling from one part of the system to another using liquid nitrogen to condense the vapors. The system was arranged so that reaction vessels could be removed from the line to perform operations such as shaking and heating, and then returned. A diagram of the apparatus is given. Measurements of radioactivity were made with a thin mica-window Geiger-Müller tube on a 64-scale circuit with a geometry of 12.5 disintegrations per count.

Control of radioactivity hazards, W. Sullivan (Clinton Laboratories, Oak Ridge, Tenn), *Chem. Eng. News* **25,** 1862–65 (1947). The principal activity hazards are neutrons, gamma, beta and X-rays, alpha emitters and fission products. General rules and procedures are given to control these hazards. Tolerances; protective clothing and decontamination thereof; protective devices; eating and smoking rules; contamination of personnel and areas; storing, handling, transportation and disposal of radioactive materials are covered in the regulations.

Radioisotopes: new tools for science, C. Thomas (Monsanto Chemical Co., St. Louis, Mo.), *Chem. Eng. News.* **25,** 1572–74 (1947). A review. Uses are suggested for radioisotopes in the fields of biology, pure and applied chemistry, chemical engineering, industrial hygiene, public health and agriculture.

Element 87, M. Perey (Laboratoire Curie, Institute du Radium, Paris), *J. chim. phys.* **43,** 155–68 (1946). A review, including some new data, of the history and discovery of element 87, and of the properties of actinium. Element 87, actinium K, was shown by Perey in 1939 to be derived from actinium by the emission of α-rays. This paper, which is the first of a series, describes in detail the chemical properties, methods of measurement,

methods of concentration from actinium-containing rare earths, and radioactive properties of Ac. The ratio of the number of atoms of Ac which disintegrate by α-ray emission (Ac $\rightarrow$ AcK) to the total number of atoms of Ac which disintegrate during this time is given as $1.2 \pm 0.1\%$. Contains 38 references.

Effects of high-energy radiation on organic compounds, M. Burton (Clinton Laboratories, Oak Ridge, Tenn.), *J. Phys. Colloid Chem.* **51,** 786–97 (1947). A critical review with 15 references. All processes characteristic of photochemical reactions of organic reactions occur also in radiation-chemical processes. In addition, ionization, discharge and decomposition reactions occur. In general, any electron in the molecule is equally susceptible to initial ionization; this is an important fact in interpretation of radiation-chemical mechanisms. Since the excitation energy generally lies in any part of the molecule, the yield of a particular product is closely related to the number of parent groups in the molecule. In the liquid state the excessive excitation energy tends to minimize the decrease in yield due to collisional deactivation and cage effect (radicals produced by rupture collide with the surrounding molecules while they are still within each other's spheres of influence, increasing the probability of primary recombination). Factors which increase the resistance of organic compounds to radiation are molecular complexity, resonance in the molecule, and all properties of the molecule such as symmetry and large size, which increase the correspondence between ionic and molecular configurations. Increase in molecular size tends to direct the decomposition via a particular route, rather than to diversify the products.

Electron microscope observations of the morphology of several gases polymerized by charged-particle bombardment, J. Watson (Shawinigan Chemicals Ltd., Shawinigan Falls, Quebec), *J. Phys. Colloid Chem.* **51,** 654–61 (1947). Polymers of acetylene (cuprene), hydrogen cyanide, and cyanogen formed by the charged-particle bombardment of the respective gases were examined by the electron microscope. Polymers formed from the three gases by alpha-ray bombardment are distinguishable by their physical appearance. Alpha-ray cuprene and hydrogen cyanide polymers appear to exist as viscous quasi-liquids, whereas the corona and catalytic cuprene and cyanogen polymers appear to be solids. Polymers were deposited as fine particles during bombardment. Statistical data concerning particle sizes are given.

The mechanism of uranium fission, M. Meyer (Brooklyn College, Brooklyn, N. Y.), *Rec. trav. chim.* **66,** 47–8 (1947). The following mechanism for uranium fission is given: (1) $_{92}U^{235} + {}_0n^1 = {}_{92}U^{236}$; (2) $_{92}U^{236} = {}_{56}Ba^{142} + {}_{36}Kr^{92} + 2{}_0n^1 + 265$ Mev; (3a) $_{52}Ba^{142} = {}_2\alpha^4 + Xe^{138} = {}_{-1}\epsilon^0 + {}_{55}Cs^{138} = {}_{-1}\epsilon^0 + {}_{56}Ba^{138}$; (3b) $_{36}Kr^{92} = 2\alpha^4 + {}_{34}Se^{88} = {}_{-1}\epsilon^0 + {}_{35}Br^{88} = {}_{-1}\epsilon^0 + {}_{36}Kr^{88} = {}_2\alpha^4 + {}_{34}Se^{84} = {}_{-1}\epsilon^0 + {}_{35}Br^{84} = {}_{-1}\epsilon^0 + {}_{36}Kr^{84}$. The energy of reaction (2) is calculated by the mass defect as 0.246 mass units, and by the packing effect per nuclear neutron as 0.313 mass units. The average of these two guesses is 0.280 mass units or 265 mev. Reactions (3a) and (3b) are highly speculative.

Ternary and quaternary fission of uranium nuclei, Tsien San-Tsiang, Ho Zah-Wei, L. Vigneron and R. Chastel (Laboratoire de Chimie Nucléaire, Collège de France, Paris), *Nature* **159,** 773–4 (1947). A systematic study of the mass and kinetic energy of ternary and quaternary fission fragments of U^{235} was carried out. Ilford Nuclear Research C_2 plates were soaked with 10% solution of uranyl nitrate and were then bombarded with slow neutrons. *Tripartition.* Usually two of the fragments are heavy (m_1, m_2), and the third one is light (m_3). The mean ranges of m_1 and m_2 are 1.9 and 2.3 cm of air, respectively, while that of m_3 has an average value of 25 cm. m_3 is emitted in a direction nearly perpendicular to that of m_1 and m_2. The

average masses of m_1 and m_2 are 99 and 131, respectively, while m_3 seems to have two values, 5 and 9. The total kinetic energy of the 3 fragments, about 155 Mev, is in good agreement with theory. A case was also observed in which m_3 is much heavier: the calculated masses of m_1, m_2 and m_3 are 127, 77 and 32, respectively. The three fragments are almost coplanar, have ionizations much higher than that of α-particles, and have a total kinetic energy of about 142 mev. *Quadripartition.* The four fragments are not coplanar. The calculated masses are $m_1 = 84$, $m_2 = 76$, $m_3 = 72$ and $m_4 = 4$, with a total kinetic energy of about 90–95 Mev.

Processes involving charged mesons, C. Lattes, H. Muirhead, G. Occhialini, C. Powell (University of Bristol), *Nature* **159,** 694–7 (1947). The study by the photographic method of mesons present as a component of cosmic radiation at high altitudes continued.

X-ray spectra of trans-uranic elements, J. Fisher, H. Flint (Postmead, Portesham, Dorset and Bedford College, University of London), *Nature* **159,** 741 (1947). An application of the principle of minimum length and time to the Rutherford-Bohr atom sets the upper limit to the atomic number, Z, somewhat lower than 96. Another theory limits Z according to the equation $Z^2/A < hc/4\sqrt{2\pi e^2} = 48.44$. From this it appears likely that nuclei occur with Z values higher than 96. Their life, however, may be short owing to the probability of spontaneous fission increasing rapidly with Z^2/A.

. . . *Abstracts above by* I. W. RUDERMAN

LIFE SCIENCES PUBLICATIONS

Absorption of radon through skin and its exhalation through the lungs, K. Lange, R. Evans, *Radiology* **48,** 514 (1947). The experiment was carried out using radon ointment on normal intact skin and the surface of large post-phlebitic leg ulcers. Breath sampling and radon measurements were done by standard techniques. Appreciable amounts of the applied ointment containing radon were absorbed through the intact skin and still more through open wounds. The authors conclude that the exhaled radon must have been transmitted internally either through circulating lymph or blood to the patient's lungs, then given off. Deep structures may thus be affected if the amounts transported by the blood system are sufficiently large. Whether this is indeed the case has not been determined by the authors.

The use of tagged antigens in immunochemical studies, R. L. Libby, *Trans. N. Y. Acad. Sci.* **9,** 248 (1947). Tobacco mosaic virus tagged with radioactive phosphorus was prepared by inoculating Turkish tobacco plants with the virus and adding radioactive Na_2HPO_4 to the nutrient solution. The radioactive TMV was injected intravenously into mice kept in metabolism cages. Analyses were made of the radioactivity of ashed samples of liver, spleen, feces, urine and carcass, using a Geiger-Müller counter and a mica-window counter tube. TMV antibody from mouse serum was plotted against time and it was found that antibody production reaches a peak between the 6th and 7th days. The half-life of the radioactive TMV is a maximum of 2 days, the exact value not being known because of some re-utilization of the radioactive phosphorus by the mice.

The effect of radiation therapy on the nocturnal secretions in patients with duodenal ulcer, E. Lævin, A. Hamann, W. Palmer, *Gastroenterology* **8,** 565 (1947). The use of roentgen rays directed over the fundus and body of the stomach has been previously demonstrated to produce a temporary depression in gastric secretion. Nine patients with uncomplicated duodenal ulcers were treated with X-ray therapy which resulted in reduced volume secreted and reduced free acidity of night secretions in seven of the nine.

At varying intervals after the therapy an average volume reduction of 47.4% was noted in 14 of 15 patients. There was marked reduction of free acidity in all patients. Comparable reduction was noted in gastric secretion response to histamine. Length of depression was in accord with previous observations.

The radiosensitivity of erythroblasts, M. Bloom, W. Bloom, *Jour. Lab. and Clin. Med.* **32,** 654 (1947). A study was made of the effect of radiation on the bone marrow of rabbits, mice, rats and chickens. X-rays, fast and slow neutrons, and internally administered radioactive elements were used. The results show that in the bone marrow of mammals exposed to X-rays, fast and slow neutrons, hematopoiesis was severely depressed, the degree varying with the dose. The marrow cells showed the same changes for the radiation from the injected radioactive isotopes as for the radiation from the external ones. Erythropoietic cells were found to be in all cases more susceptible than the megakaryocytes.

Chickens exposed to X-rays reacted in the same manner. The erythroblasts were as radiosensitive as the smaller lymphocytes of the nodules. Fat cells, free macrophages and reticular cells were completely radioresistant to the dosage used.

Distribution of C^{14} in photosynthesizing barley seedlings, S. Aronoff, A. Benson, W. Hassid, M. Calvin, *Science* **105,** 664 (1947). Two sets of young barley plants, one from which the primary and secondary roots and hypocotyl had been cut and the other complete except for secondary roots, were given radioactive carbon dioxide for assimilation under a bank of artificial lights. Conditions were specific as to time, oxygen pressure and carbon dioxide pressure, which if changed would bring about somewhat different results. Varying amounts of C^{14} were incorporated by the plant constituents. Radioactivity was determined directly in some cases and by difference in others; thus it was determined directly that in plants with roots, 25% of the total C^{14} in the plants was absorbed by the sugars and it was calculated that the lignins absorbed 8.3%. Differences occurred in both the total C^{14} absorbed by the two types of plants and also in the relative percentages absorbed by the corresponding constituents of the plants.

The atom bomb—hazards incident to its use, S. Warren, F. Bryan, R. Buettner, *Indus. Med.* **16,** 275 (1947). Discusses effects of the atom bomb, such as damage done by heat, radiation and pressure upon buildings and radiation sickness caused. Suggestions offered to minimize danger of atom-bomb attack include strongly constructed reinforced-concrete shelters well below ground, decentralized medical facilities, industrial plants and civilian housing, concrete housings without combustible interiors, and highly mobile civilian units able to do fire-fighting, rescue work, radiation detection and rehabilitation work. Radiation effects of alpha, beta and gamma rays and neutrons are compared as well as their effect on tissues of varying specialization. It is concluded that physicians would face many difficulties because of the varied and complex damage done to the body.

The influence of heavy water on growth, morphology and fermentation reactions of eberthella typhosa, H. Chance and W. Allen, *Jour. of Bact.* **51,** 547 (1947). Studies were made using 8% heavy water, as determined by the micro specific gravity method, with nutrient agar, *d*-glucose agar and *d*-glucose broth. No observable changes were seen in cells from nutrient agar made with either normal or heavy water but changes were observed when *d*-glucose agar made up with heavy water was used. Nigrosin smear slides were made every hour and later changed to periods varying from 4 to 24 hr. Hanging drop observations were made upon cells of heavy water *d*-glucose broth and controls.

Gross morphological changes were noticed in cells grown on 8% heavy water *d*-glucose agar. Many atypical cell forms were observed. Small bud-

like structures appeared on the cells; granulation was very prominent. The principal method of reproduction was binary fission although there was much budding present. In spite of the morphological changes there was no physiological evidence of change as evidenced by fermentation reactions. Some growth facilities were changed. Old heavy water cultures would not grow on agar slants but would grow in broth.

Radio-autographic studies of the distribution of lewisite and mustard gas in skin and eye tissues, D. Axelrod, J. Hamilton, *Am. J. of Path.* **23,** 389 (1947). Deposition in tissues of the eye and skin of the war gases, lewisite and mustard, labeled with radioactive arsenic and sulfur respectively, were studied. After exposure, tissues were fixed and cut into sections 10 to 15 microns thick. Sections were mounted on slides and covered with No-Screen X-ray film (Agfa), and exposed for one to three weeks. The film was developed and the tissues were stained with hematoxylin and eosin.

Comparison of the tissue sections and corresponding films shows that in human skin, lewisite is fixed primarily in the epidermis and that massive necrosis of the epidermal layer and corium results. Mustard gas was found to be fixed in the epidermis and dermis of the skin. Concentration in the blood vessels and hair follicles could not be determined because of excessive exposure of the film by the mustard gas. Exposure of pig skin to mustard gas showed large concentrations in the epidermis, dermis, hair follicles and adjacent sebaceous glands and blood vessels. Exposure to lewisite showed concentrations to be primarily hair and superficially located hair follicles. In all cases, mustard gas penetrated the skin far more deeply than lewisite for corresponding length of exposure.

. . . *Abstracts above by* BERNARD KANNER

Applications of recent advances in nuclear physics to cancer research, T. Mitchell, *Brit. J. Cancer* **1,** 1, (1947). A review containing much recent published information and with much emphasis on different research aspects. Various methods of isotope production such as the use of the cyclotron and chain-reacting piles are compared and the isotopes thus produced evaluated medically and biologically. Tables are given showing the stable and radioactive isotopes of research interest. These tables include the nature of the isotope reaction involved, type radiation emitted, half-life and energy of radiation.

Radioactive sources in radiotherapy (of which Co^{60} with a half life of 5.3 years is promising and Ta^{182}, with a half-life of 97 years, also important) are discussed. Gamma radiation from Co^{60} is approximately monochromatic and of slightly higher mean energy than the usual filtered gamma radiation from Ra. The accompanying beta radiation is relatively soft and easily removed by filtration.

Uptake of radioactive iron in iron-deficient and in B_6-deficient pigs before and after acute inflammation, M. Wentrobe, G. Greenberg, S. Humphreys, H. Ashenbrucker, W. Worth, R. Kranier, *J. Clin. Invest.* **26,** 103 (1947). Growing pigs were injected intravenously with radioactive iron in amounts corresponding to the quantity absorbed by a human per day and to the quantity derived each day from hemoglobin catabolism. Sterile abscesses were produced by turpentine injections, bacterial infections by daily intramuscular injections of S. aurens and E. coli, and burns by placing a flask of boiling water on flank of the animal.

The authors have shown that the uptake of Fe^{59} is rapid and complete in iron deficiency, slow and even negligible if large doses are used in B_6 deficiency, and intermediate in normal animals. In the presence of inflammation, however, the uptake of iron by the iron-deficient pig is markedly impaired. Supplementing the pyridoxine-deficient animal with pyridoxine causes a rapid

and efficient uptake of iron which is rapidly reduced by the presence of infection. The authors conclude that the anemia of infection is caused by impaired hemoglobin production. This anemia appears only when the outworn red corpuscles must be replaced.

The circulating red-cell and plasma volume and the distribution of blood in large and minute vessels in experimental shock in dogs, measured by radioactive isotopes of iron and iodine, J. Gibson 2nd, A. Seligman, W. Peacock, J. Fine, J. Aub, R. Evans, *J. Clin. Invest.* **26,** 126 (1947). Measurements of total circulating red-cell and plasma volume and of the distribution of blood in large and minute vessels were made in dogs in experimental shock by means of techniques employing Evans blue dye for total plasma volume, radioactive iron for circulating red-cell volume and radioactive iodine for quantity of circulating plasma.

The authors found that there is always a greater reduction in circulating red cells and plasma than can be accounted for by measured external blood loss. In certain types of shock, a part of this discrepancy in blood volume may be due to loss into damaged areas or by intestinal bleeding. Regardless of etiology, there is a widespread trapping of red cells within the minute vessels of all organs in the body which, in effect, is a reduction of capillary blood flow through all organs. Trapping of a small portion may result in a fatal reduction in capillary flow. There is an abnormal distribution of whole blood between the large and minute vessels which is not reflected by changes in the arterial hematocrit. There are marked deviations from normal in the hematocrit of large- and small-vessel blood, and these are directly related to changes in the arterial hematocrit. The degree of cell trapping present does not parallel the reduction in total blood volume, but is related to the reduction in mean arterial pressure. However this correlation need not apply when the hematocrit is abnormally high.

The authors believe that therapy of shock should be directed not only towards restoration of total blood volume, but also towards the resumption and maintenance of normal capillary flow.

Fate of injected radioactive iron in the presence of inflammation, G. Greenberg, H. Ashenbrucker, M. Lauritsen, M. Wentrobe, *J. Clin. Invest.* **26,** 121 (1947). Radioactive iron was injected intravenously into normal rats, in rats with acute inflammation, also in dogs of both types. After a period of time, blood, tissue and exudates were analyzed for radioactivity. Rats with inflammation showed retarded hemopoiesis and increased deposition of Fe^{59} in liver and spleen as compared to control animals. There appears to be an inverse correlation between Fe^{59} in the liver and in the blood of both normal rats and animals with inflammation. No significant quantity of Fe^{59} is diverted to the inflamed area. Insignificant percentages of large doses of intravenously injected Fe^{59} were found in the exudate of a sterile abscess and in the excreta of a dog that had received turpentine intramuscularly.

The authors conclude that the major diversion of plasma iron in infected animals is to the ordinary storage tissues, primarily the liver. Also this diversion is related to hypoferremia.

The fate of radioactive tartar emetic administered to human subjects, F. Bartter, D. Cowee, H. Most, A. Ness, S. Forbush, *Amer. J. Trop. Med.* **27,** 403 (1947). This deals with results of administering single doses of tartar emetic to human volunteer subjects with reference to rate of excretion and levels found in the blood. The radioactive antimony was obtained by bombardment of antimony metal with deuterons in the cyclotron. The naturally occurring isotopes Sb^{123} and Sb^{121} going to Sb^{124} and Sb^{122} respectively. The former has a half-life of 60 days and the latter 2.8 days. Both give rise to a high-energy gamma ray on disintegration, a property that facilitates

detection even in the presence of organic matter.

Impurities of the target were eliminated, carrier added and Sb synthesized into tartar emetic in the chemical laboratory of the National Institute of Health. Radioactivity of standards as well as specifications for analysis were determined in the Carnegie Institution by means of Geiger counters and scaling circuits.

Results show an extremely rapid fall of Sb level in the plasma following intravenous administration, which may explain the failures of therapy with infrequent dosage. Following one intravenal dose, a rapid elimination by urine and feces for the first two days was followed by a slower and relatively steady rate for the following five days. 80% was eliminated via urine and 20% via gastro-intestinal system. 12% was eliminated in 24 hours and 30% by the end of the first week. Analogous results of multiple injections in man and dog suggest that the basic blood level may be controlled by adjusting size and frequency of dose.

. . . *Abstracts above by* IRWIN CLARK

PHYSICAL PUBLICATIONS

Yield of photo-neutrons from U^{235} fission products in heavy water, Bernstein, et al., *Phys. Rev.* **71,** 573–581 (1947). High-energy gamma rays emitted in U^{235} fission were studied by observing neutrons from the D (γ,n) reaction. Results are given for processes whose half-lives range from 2.5 sec to 53 hr. One to two γ-rays of energy above 2.2 Mev are emitted by fission products per fission with half-lives greater than 1 sec.

A calorimetric determination of the energy produced by plutonium 239, Stout, Jones, *Phys. Rev.* **71,** 582–585 (1947). Pu^{239} is a natural α-emitter. Half-life has been determined by finding (a) the energy of individual α-particles (from range) and (b) total energy given off by a known sample of plutonium (from the amount of liquid nitrogen evaporated, as compared with the amount evaporated by a known quantity of electrical energy). These two results give the number of α-particles in a given time from a given number of Pu^{239} atoms, and thus the disintegration constant and half-life (2.411×10^4 years).

Radioactivity of Be^{10}, Levinger, Meiners, *Phys. Rev.* **71,** 586–588 (1947). Gives lifetime between 10^6 and 10^7 years and max. energy (650 kev) of the beta-radioactivity of Be^{10}.

The transmission of slow neutrons through monocrystalline materials, Fermi, Sturm, Sachs, *Phys. Rev.* **71,** 589–594 (1947). Crystals used were Be and BeO, neutrons from 0.003–0.02 e.v. being obtained by mechanical selector (low energy) and crystal spectrometer (higher energy). Scattering cross-sections agree with those to be expected from the theory of elastic scattering in crystals, outlined in the article.

Range-momentum measurements of particles emitted in nuclear disintegrations induced by 100-Mev X-rays, Klaiber, Luebke, Baldwin, *Phys. Rev.* **71,** 649–656 (1947).

Cloud-chamber studies of multiple scattering of protons in air, Luebke, Klaiber, Baldwin, *Phys. Rev.* **71,** 657–660 (1947).

Interference phenomena of slow neutrons, Fermi, Marshall, *Phys. Rev.* **71,** 666–667 (1947). Investigations described had the particular purpose of finding whether the phase change of the scattered neutron wave is near 0° or 180° for various elements by measuring (1) Bragg reflection, (2) scattering cross-sections, (3) limiting reflection angles. Elements investigated were Ba, Be, C, Ca, Cu, F, Fe, Mg, N, Ni, O, Pb, S, Zn, Li, Mn, I, Br, Cl, K, Na.

The article also gives an outline of the theoretical considerations involved in the interference phenomena of slow

neutrons (occurring in crystals whose internuclear distance compares with the neutron wavelength).

The double-focusing beta-ray spectrometer, Shull and Dennison, *Phys. Rev.* **71,** 681–687 (1947). This magnetic focusing system allows large beam without decreased resolving power, also allowing focusing of high-energy particles. The condition that the first-order defocusing term vanish is given in terms of the form of the magnetic field. Second-order defocusing can be almost entirely eliminated by a further shaping of the magnetic field. Images obtained are compared with those from semicircular focusing, and resolving power is found to be much higher.

The variational method for asymptotic neutron densities, Marshak, *Phys. Rev.* **71,** 688–693 (1947). Equations for certain neutron-diffusion problems treated by variational methods.

The neutron-absorbing isotopes in gladolinium and samarium, Lapp, Van Horn, Dempster, *Phys. Rev.* **71,** 745–747 (1947).

Diffraction of neutrons by a single crystal, Zinn, *Phys. Rev.* **71,** 752–757 (1947). A neutron monochromator consisting of a single calcite crystal was used to investigate resonance absorptions, the intensity of the neutron beam from a pile being great enough for Bragg reflection to be observed in enriched BF_3 counters.

Measurement of neutron cross-sections with a crystal spectrometer, Sturm, *Phys. Rev.* **71,** 757–776 (1947). A LiF crystal was used as a monochromator to determine cross-sections between 0.04 and 65.0 e.v. for various elements, showing the Breit-Wigner absorption levels in Rh, Au, Ir, Gd, Sm, and Eu. Slope of the graph indicated levels at negative energies in a number of cases. A BF_3 counter was used, with fission monitors.

The production of nucleons by cosmic radiation, Korff and Hamermesh, *Phys. Rev.* **71,** 842–845 (1947).

Some stationary distributions of neutrons in an infinite medium, Verde, Wick, *Phys. Rev.* **71,** 852–864 (1947).

The theory of alpha-radioactivity, Preston, *Phys. Rev.* **71,** 865–877 (1947). A rigorous development of the one-body theory with a rectangular potential well, using the method of steepest descent. Solutions for the case of the angular momentum 1 not equal to zero are also obtained. The nuclear radius and the depth of the potential well determine the decay constant and the energy of the emitted alpha particles.

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These particular experiments permit accurate determination of the intensities of gamma-lines from RaC and Th(C + C″), with energies exceeding $2mc^2$, from the recoil electron spectra, as determined with a magnetic spectrograph; and data were utilized to verify various phenomena of interaction of high-energy gammas with matter. Positron spectra from internal conversion were also used, giving the gamma-ray energy $h\nu = E + 2mc^2$, E being the positron energy at which the number of positrons drops abruptly to zero. For gammas of energy less than $2mc^2$, observations are made on electrons knocked out of the atom in internal conversion.

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$$\Delta m/m = \tfrac{1}{250}$$

has been made of test samples.

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BOOKS

PUBLICATIONS OF 1947

KAMEN, MARTIN D., **Radioactive Tracers in Biology,** Academic Press Inc., New York, 1947, 281 p.

The author, generally recognized as one of the world's pioneers in nucleonic biology, calls his subject "An Introduction to Tracer Methodology." He does full justice to his three objectives: (1) to provide an introduction or review of those concepts in nuclear physics, an understanding of which is basic to the intelligent application of tracer methods in biology. (2) to present a systematic and critical survey of existing tracer methods, and (3) to indicate potentialities and limitations of these methods to biological problems. It is an indispensible text and reference book for every life scientist. Electronic engineers, too, will find it contains essential information for the design of instruments acceptable to this field.

LEA, D. E., **Actions of Radiations on Living Cells,** Cambridge University Press, London, 1947, 402 p.

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MILLIKAN, ROBERT A., **Electrons (+ and −), Protons, Photons, Neutrons, Mesotrons, and Cosmic Rays,** University of Chicago Press, Chicago, revised 1947, 642 p.

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A loose-leaf service kept up to date, as additional regulations are made, in collaboration with legal staff of Pike & Fischer, Washington, D. C. Contents stem from government regulations, domestic and foreign. It is a service bringing vigilance, arrangement, classification, correlation, interpretation, annotation, and indexing. Of interest to public utilities, medical, chemical and other manufacturers, engineers, domestic and foreign government agencies, scientific schools, and patent attorneys.

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BURK, ROBERT E., **Advances in Nuclear Chemistry and Theoretical Organic Chemistry,** Interscience Publishers, Inc., New York, 1945, 165 p.

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CORK, JAMES MOULE, **Radioactivity and Nuclear Physics,** J. W. Edwards, Publisher, Ann Arbor, Michigan, 1946, 175 p.

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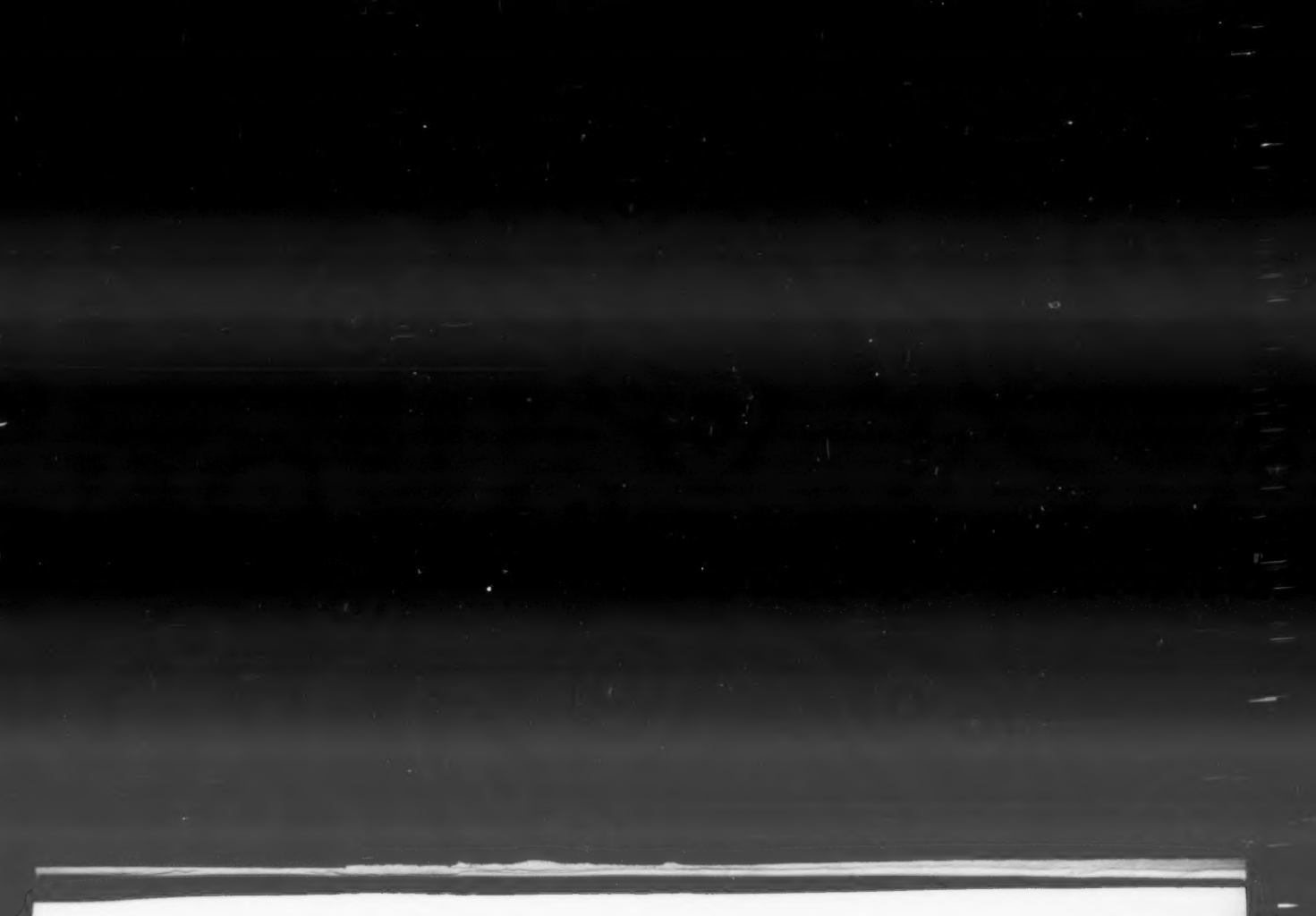
Basic atomic pile theory, design, statistics, control, operations, and applications. Also presents background material and the chemistry of the heavy elements and the fission process. Twelve chapters, each by an authority in his field.